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AN EXPERIMENT TO CORRELATE STRUMMING AND FISHBITE EVENTS ON DEEP OCEAN MOORINGS

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Eric J. Softley
John F. Dilley
David A. Rogers

May, 1977

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A deep water experiment was designed to provide information on the correlation between cable fishbite and cable strumming. Two moorings, one with anti-strumming fairings and one without, with subsurface floats were deployed in 1870 m of water in the Tongue of the Ocean. Data on cable damage in the upper half of the mooring cable and strumming at the top of the cable were collected over the three month deployment period.

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While the lack of fishbites prevented any conclusions on fishbite causes, strumming data for long faired and unfaired cables in the ocean was obtained. In addition, data on strumming was also obtained from auxiliary experiments.

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ABSTRACT

A deep water experiment was designed to provide information on the correlation between cable fishbite and cable strumming. Two moorings, one with anti-strumming fairings and one without, with subsurface floats were deployed in 1870m of water in the Tongue of the Ocean. Data on cable damage in the upper half of the mooring cable and strumming at the top of the cable were collected over the three month deployment period. While the lack of fishbites prevented any conclusions on fishbite causes, strumming data for long faired and unfaired cables in the ocean was obtained. In addition, data on strumming was also obtained from auxiliary experiments.

1.0 INTRODUCTION

1.1 Project Description

This project consisted of two phases. During the first phase the feasibility of detecting cable damage due to fishbite and monitoring cable strumming was demonstrated and the design of the breadboard electronics required to accomplish these measurements was achieved. During the second phase the experiment hardware was assembled, deployed, retrieved, and the data analyzed.

The feasibility study centered on successful field test of the time domain reflectometer (TDR) used to detect the position and extent of cable damage. The important feature of this technique is that it can "see" through cuts in the cable and thus can record a series of cuts in the same conductor completely. These field tests were also supported by laboratory tests of this equipment. The feasibility study also consisted of demonstrating a means of monitoring cable strumming. This was accomplished in the laboratory using strain gages mounted on the cable terminator. Some strumming analyses were done in order to be able to better understand the cable behavior. Another part of the feasibility phase of the study involved a survey of the available fishbite literature. We found that sharks are responsible for a large number of fishbite incidents and the worst damage and that low frequency sound is a most likely attractant.

During the second and main phase of the project, the electronics necessary to acquire, process, and store the data were assembled and checked out. The instrumented mooring line was assembled. To improve reliability in the ocean, a series of laboratory and field tests were conducted on cable damage detection and strumming. These tests and field experiments are described in Sections 4 and 5. The strumming data obtained in these tests is described and discussed in Section 6.

While the main goal of this study was to obtain data on the correlation between cable strumming and fishbite, we were unfortunate in that no bites were observed on either mooring cable; not on the unfaired strumming cable nor on the faired cable. Care was taken to moor in an area where sharks are known to be present. The moorings were in place for a full three months. The data showed that the unfaired cable did indeed strum.

1.2 Review of Fishbite Literature

A survey (Reference 1) of the available domestic literature was conducted to ascertain which species were involved in cable damage, which cables were more susceptable to damage, what were the potential factors influencing attack on cables and potential countermeasures. A summary of these facts is presented in Table 1. Sharks head the list of those that inflict the greatest damage on marine cables. Unarmored natural fiber rope is the most prone to serious damage from marine attack. The best protection for a cable is a sleeve made of corrosion resistant high strength alloy but the additional cost of this protection can be prohibitive.

Of all the potential factors influencing attack on cables by sharks and other pelagic species, the one that seems most likely is low frequency sound, such as that generated by a cable strumming. Low frequency sound generators have been demonstrated to be very efficient at attracting large number of sharks. However, once there, the sharks do not attack the generator. It is possible that some motion of the object is also required to precipitate attack.

Other potential effects include four phenomena that are known to be factors in isolated cases but that seem to be of second order in importance. An additional two factors deal with location. These factors are; 1) bio-luminesence produced by organisms attached to the cable; 2) other visual cues such as color, geometry and motion; 3) olfactory attractants from the cable or from marine organisms attached to the cable; 4) electromagnetic effects generated by the electric current in the cable or by a galvanic current set up by dissimilar metals in the cable; 5) local temperature effects,

a higher biting frequency has been reported in the thermocline. This can be attributed to a higher concentration of nutrients and food web of the cable biting species. Sharks are also known to migrate seasonally with the warm water. 6) Depth, sharks are found from 0 to approximately 400 m. Paralepidids are considered deep water species and have been recovered from as deep as 2150 m. Sea turtles are depth limited and are found in the 0-25 m depth range.

There are several potential countermeasures that can be used in an attempt to minimize cable damage due to attack by marine species. Antistrumming devices such as polyethylene strips effectively eliminate the low frequency sound generation. Cable armor, either plastic or metal, could be used to harden the cable surface. Chemical additives applied to the outer cable jacket could be used to prevent biological fouling or could serve as a shark repellant if the right material were found.

2.0 MOORING AND CABLE DESIGN

A controlled experiment was designed to obtain ocean data on the correlation between cable fishbite and cable strumming. Two deep water (1870 m) moorings were implanted in the Tongue of the Ocean. The moorings, depicted in Figure 1, consist of a subsurface float with a data package attached to the bottom; a multiconductor cable, one with antistrumming fairing and one without; an acoustic release between the multiconductor cable and the steel mooring cable. At the bottom of the moorings are a short section of nylon line to take up any shock loading during the deployment sequence, a short length of chain, and a 1000 lb. anchor. The figure gives the mooring lengths involved in the system and the net underwater weight in pounds of the components in the mooring. The subsurface floats, the steel mooring cables, and the anchors were all parts from surplus Hermes Nutmeg buoy systems.

The data package contains all the electronics for acquisition, processing, and recording the cable damage and strumming data. The design of the electronics and the techniques for data processing and storage are discussed in detail in Section 3.0. The strumming sensor/cable terminator is attached to the bottom of the data package.

The strumming sensor shown in Figure 2 was custom designed for this application. It consists of semiconductor strain gauges mounted on a steel beam through which the cable passes. A Teflon sleeve is attached to the end to prevent excess bending strain and the assembly covered with a polyurethane boot. The sensor measures bending strain caused by the lateral vibrations of the cable. The strumming sensor also acts as a cable terminator and breakout and provide a water tight seal where the cable enters the instrument package.

The multiconductor mooring cable has 12 AWG #20 conductors that surround a 1 x 19, 5/32" galvanized aircraft wire rope covered with a polyvinyl chloride jacket--see Figure 3. The conductors are covered with a mylar tape and an outer jacket of black low density polyethylene.

The anti-strumming fairings are made out of 1.5 mm thick L.D.P.E. sheet. The configuration is shown in Figure 3. The strips were initially glued to the cable jacket but finally a technique of attaching them using nylon tiewraps was derived and this technique proved cheaper and faster. As a measure of cost the cable, purchased in 1975, cost approximate $1/ft. and the antistrumming fairing cost $0.80/ft. (total cost).

3.0 ELECTRONICS

3.1 Data Package

The data processing and recording electronics, power supplies and timing and control circuitry for both the strumming and non-strumming cable moorings are essentially identical. They are housed in anodized aluminum cannisters which attach to the subsurface floats. Overall length of the cannister is 91 cm. and the inside diameter is 20 cm. The data package is assembled on four shelves which are mounted on three 1.25 cm threaded rods that attach to a plate which constitutes the bottom cover of the cannister. This allows easy attachment of the mooring line prior to deployment while minimizing the water tight sealing problem. A photograph of the inside of one of the data packages just prior to deployment with the strumming test cable attached is presented in Figure 4. The timing and signal conditioning electronics are constructed on printed circuit cards mounted in the card rack chassis at the bottom shelf (nearest the cable entry). The next shelf holds a time domain reflectometer (TDR). The second shelf from the top mounts a cassette-type magnetic tape recorder and at the top of the package are the batteries which constitute the basic system power source.

The mooring cable wires, together with the leads from the strain gage instrumented strumming sensor, are terminated in a multi-pin Bendix plug which mates them to the instrument package signal conditioning electronics, while the potted, O-ring sealed, mooring cable terminator is fastened to the bottom cannister cover. Also mounted in the bottom cover is a Glenair multi-pin connector for the external test unit cable so that system operation can be monitored and proper performance assured prior to deployment.

3.2 Data Processing and Storage

The basic design requirements of the data package electronics were: (1) an operational lifetime of three months using a self-contained power supply; (2) sufficiently frequent sampling to assure good correlation of bite occurrences with anticipated cycle time of ocean current induced strumming; (3) provision of a timing system reference of good accuracy; and (4) the accomplishment of the program objectives with a relatively low cost, yet reliable instrument package. Magnetic tape recording of the test data was chosen as representing the most satisfactory solution to the data recording requirement since it provided a permanent record, imposed no standby power drain, could provide simultaneous recording of TDR, strumming and time information, and was readily available commercially in reliable and relatively low cost equipment.

In order to observe strumming at frequencies as low as one Hertz, a sample recording time of at least two seconds is necessary. Also, for optimum signal-to-noise ratio and good resolution from the TDR a sweep time of about 250 milliseconds is desirable. Since each of the twelve wires in the cable must be monitored each time the system is powered up, at least three seconds are required to check the cable. Finally, a sample should be taken at least every two hours to avoid missing significant changes in strumming due to current fluctuations. Thus, the total data recording time required for a three month deployment is a minimum of about 3200 seconds which is consistent with the one hour of playing time available on a standard data cassette using a tape speed of 4.76 cm/sec. (1 7/8 ips) which is standard for audio cassette recorders. Analog data recording was chosen as being most appropriate to this application since highly accurate amplitude information is not necessary. More important are detectability and time resolution of discontinuities in the TDR signal and frequency distribution of the strumming information. Thus, more efficient utilization of of the tape is attainable using analog recording.

In order to maximize the signal-to-noise ratio and dynamic range of the recorded data and preserve the essentially dc low frequency response of the data frequency modulation (FM) recording was used.

To minimize the size, weight and cost of the battery requirement, the system clock - which had to operate continuously - was constructed from complementary metal-oxide semiconductor (CMOS) integrated circuits having very low power consumption. The clock is crystal controlled with a basic timing accuracy of $\pm$ 0.001% and a stability of $\pm$ 0.001% over a $0^{o}C$ temperature range. This assured a cumulative timing error over the three month deployment of about 1 minute, far less than the minimum recorded time increment of 15 minutes.

Standby power drain of the system is a modest 35 milliwatts when operated from a nominal 15 volt battery pack - a total energy requirement of about 75 watt-hours over three months. Operating power required to record data is about 12 watts, but since the total "on" time is only an hour over the three months, this only adds 12 watt-hours, to give a total battery requirement of about 87 watt-hours. (It does, however, impose the requirement that the battery be able to supply a peak current of almost an ampere). A battery pack made up of eight Eveready No. 560 Alkaline batteries provides about four times the total nominal three month energy requirement and is well able to supply the peak power demand. It occupies only about 0.007 cubic meters and weighs about 5.7 kilograms. Some of the available excess capacity was used in the course of conducting extensive pre-deployment testing of the system.

3.3 Time Domain Reflectometer

A commercially available (until it was discontinued in 1975) time domain reflectometer, the Tektronix Model 1501 was purchased to provide the means by which the test cable was examined for discontinuities. The TDR operates by imposing an essentially instantaneous step of voltage to the transmission line consisting of the particular wire being examined and a return path con-

sisting of all the other wires, the center strength member and the ocean surrounding the cable. This step propagates down the transmission line until it encounters a discontinuity such as a break, short circuit or a lesser change in impedance from which point some or all of the signal is reflected back to the source. Since the propagation velocity of the signal is nominally constant for a given cable, the location of a discontinuity can be determined by measuring the elasped time between the imposition of the voltage step and the arrival of its reflected component. Also, the nature of the discontinuity (open, short, increase or decrease in impedance) can be determined from the amplitude and polarity of the reflected signal. In a long cable which has significant series resistance, there is attenuation of both the applied and reflected signals which is also frequency dependent. Thus, the impedance of the discontinuity is difficult to measure accurately and its occurrence is more difficult to identify because of rounding off of the leading edge of the reflection due to the increasing attenuation with increasing frequency. A distance versus time wave diagram is shown in Figure 5 which illustrates the relationship between the TDR trace and the cuts for a coaxial cable in the ocean. The cable was open-ended and contained three cuts in its outer conductor.

Since the elapsed time between imposition of a voltage step at the upper end of the cable and receipt of the reflected wave from the short circuited bottom end of the cable is only about 9 microseconds, it is not possible to record the reflected voltage waveform during a single pulse. Instead, the TDR generates the step at about a 10-12 kilohertz rate and samples the return signal during a one nanosecond interval which is progressively delayed in time further from the transmitted step for each successive sample. The sampled voltage is stored in a capacitor between pulses. The total number of samples (in our system) is about 2000 for the 900 meter long cable, and the potential spatial resolution of a discontinuity is about 1/2 meter.

3.4 Strumming Sensor

The upper end of the mooring cable attaches to the data cannister by means of a cylindrical beam which is instrumented with temperature compensated strain gages to monitor bending in two orthogonal directions. These sensors were calibrated using a vibrating test cable in the lab. The strain gage bridges are completed and balanced inside the data package and the alternating component of the resultant strain signal is amplified to a level adequate to operate the FM record amplifiers. Frequency response extends from about one Hertz to about 200 Hertz.

One difference in the strumming sensors in the two instrumented moorings was that the sensitivity of the recording system for the faired cable system was about twice as great as that for the strumming system.

3.5 Data Sequence

System timing was under control of a 0.01 Hertz crystal controlled clock oscillator whose output was divided down to produce binary-coded elapsed time (from power up) in quarter hour increments to a full scale of 128 days. Fourteen bits are required for this data. The system for computer decoding of this data was designed to handle a sixteen bit work containing twelve data bits, a parity bit and a three bit word sync information. It was therefore necessary to record time in two, alternately recorded, words. Four of the five remaining bits available in each word were used to provide identification of the wire being interrogated. Word rate was about ten per second or about twice as fast as the rate of cable wire interrogation by the TDR, thus assuring accurate identification of which wire, if any, had a discontinuity and facilitating establishment of the time of occurrence.

The elapsed time clock, which is continuously powered, is also used to control turn-on of the TDR, tape recorder and signal conditioning electronics every two hours for three and a half seconds.

3.6 Data Recording

A quality cassette tape transport marketed by Individualized Instruction Inc. was utilized for data recording at a regulated speed of 4.762 centimeters per second. Certified data cassettes containing 183 meters of tape provided the recording medium. A four track head was necessary in order to provide simultaneous recording of time and wire identification, strumming from each of the two strumming sensors and TDR output information.

The FM record amplifiers consisted of Type 566 integrated circuit voltage controlled oscillators operating at a nominal center frequency of 3500 Hz with full-scale deviation of $\pm$ 40%. The nominal frequency response was thus about 500 Hz which was adequate to record an actual TDR discontinuity resolution of about 3 meters over the 900 meter cable length.

A block diagram of the complete buoy electronics is shown in Figure 6. which essentially summarizes the foregoing discussion. When power is turned on at the beginning of each data logging period, the shift register (SR) clock frequency is recorded for about 0.8 seconds on the timing track of the recorder to assure synchronization of the decoder during playback. Then the TDR sweep counter is reset and cable wire interrogation begins and takes place sequentially.

4.0 CABLE DAMAGE DETECTION TESTS

The time domain reflectometer that is used to detect cable damage is an electronic device that sends very short (~ nanoseconds) current pulses down the cable and records the return reflections of this pulse caused by impedence changes in the conductor. Thus the position of the damage can be determined by the time of return. The pulse will span gaps in a conductor when the gap is filled with a conducting liquid such as sea water. This allows the instrument to record a series of cuts in the same conductor.

The initial tests on the TDR were done in the laboratory at Valley Forge. A 71 ft., open ended piece of RG58 coaxial cable was used as a test specimen. A cut was made in the cable and this section of the cable was placed in a sea water bath. The TDR traces are basically the same as the results obtained later in the ocean.

In December 1974, a field trip to the Bahamas was taken for another program and, while there, a test of the TDR system was made. A 320 ft. length of RG54C-U coaxial cable was used as a test cable. Cuts were made in the cable and a measurement was taken after every cut. The data are shown in Figure 7. The top trace shows the uncut cable with the beginning and the end of the cable indicated. The next trace down shows the location of the first cut, it being about 50 ft. from the bottom of the cable. The next cut was made about 70 ft. closer to the surface and the TDR. The third cut was up another 70 ft. As can be seen in the bottom trace, all three cuts can be resolved with little degradation in the signal.

5.0 FIELD EXPERIMENTS

5.1 Chesapeake Bay Strumming Tests

In May of 1976, a location in the Chesapeake Bay was chosen to evaluate the strumming sensor and the performance of the anti-strumming fairing. The experiment was performed aboard a 35 ft. sailing auxiliary, see Figure 8. The location was south of the Annapolis Bay Bridge, see Figure 9. The ship was anchored in 130 feet of water. Two 100 ft. cables were used for the strumming measurements; one faired and the second unfaired. These were attached to a 500 lb. anchor along with a nylon anchor crown line. The crown line and the cable not being tested were allowed to drift downstream, supported by small surface floats, see Figure 10. Current measurements were taken using both a prop-type and an inclinometer type currentmeters.

The first series of measurements were made on the unfaired cable. Visual observations of the strain gage output on the oscilloscope were made every half hour. This data was also recorded every hour on magnetic tape. There was a strong ebb current (> 1 kt.) flowing during this first series. Several tidal cycles were sampled but the current, during the data collection period on the anti-strumming faired cable never reached the values attained during the series on the unfaired cable. The strumming data is discussed in Section 6.2.

5.2 Deployment of Test Moorings (Tongue of the Ocean)

The site chosen for the test moorings was in the Tongue of the Oceans at 77^{o} 52' W and 25^{o} 10' N. Several factors influenced the site selection. All the known biters were represented in the local population. Also the currents were such that strong periodic excitation of the cable was expected due to a combination of tidal and mean flows. Current data in (Reference 2) shows an average surface current of 0.5 kt. in summer and fall, see Figure 11. The subsurface current profiles shown in Figure 12 indicates speeds between 0.2 and 0.8 kt.

Additional factors in the site selection were a depth of 2000 m with a nearly flat bottom and the easy access from Miami, Florida. These two factors aided in maintaining low deployment cost.

The two fishbite moorings depicted in Figure 1 were deployed on the 24th and 25th of July, 1976 using the R/V Venture. The location is shown in Figure 13. They were moored 1000 m apart in 1870 m of water with the subsurface floats initially at 27 and 39 m below the surface.

The mooring technique was anchor-last. An auxiliary float with enough buoyancy to float the whole system was attached to the primary float with 10 m of nylon line. Figure 14 shows the two units just prior to being overboarded. The buoy has the instrument cannister attached with the strumming monitor/cable terminator at the bottom. The electronics shown in Figure 4 were tested and activated approximately 12 hours prior to their deployments.

Once the buoy and float were in the water Figure 15, (note 1000 lb. anchor in lower right hand corner), they were towed out with a skiff (Figure 16) and the mooring line was deployed (Figure 17). The fairing was not damaged during deployment over the rollers. The acoustic releases were inserted into the moorings, between the multiconductor cable and the steel cable. The anchor was lowered with a steel crown line and an additional acoustic release. When the anchor reached a depth of 1540 m, the release was fired and the anchor dropped (See figure 18). At this point, the mooring was being kept afloat by the auxiliary float. Final bathymetry soundings were made to find the final depth. When found, the auxiliary float was removed, and the mooring was lowered into position.

The data collection period lasted three months. The upper halves of the two moorings were retrieved on October 27, 1976. LORAN A was used for navigation. The acoustic release on each mooring was fired, bringing the subsurface float with the instrument package to the surface with the attached multiconductor cable and acoustic release. The floats were lifted aboard (see Figure 19) and the cables reeled in, upper end first. The cables were inspected as they came in. Only one major slash at the upper end of the unfaired cable

was noted with some small indentations at the lower end. The faired cable appeared completely untouched and, except for fouling in the light zone, was as if unused.

5.3 Long Wire Strumming

Preliminary analysis indicated that long, constant cross section moorings could strum with extensive signatures. The data recordings obtained from the above "fishbite" moorings were intended to verify the existence and amplitudes of strumming, per se, and are short because of tape recorder limitations. Longer recordings are needed for detailed fine resolution spectral analysis. Hence, following retrieval of the fishbite buoys an experiment was performed at that site to record long wire strumming.

The recovery ship was anchored in 1960 m of water. A wire 500 m in length was deployed from the vessel with a strumming sensor at its upper termination. A Nisken "winged" current meter was attached to the wire 250 m deep. (A second current meter was deployed at 50 m depth on a separate line.) Hence the strumming cable could be considered to have a strong nodal point at 250 m. Data was recorded continuously on a Sangamo 14 track recorder for some 18 hours. The ship motion was monitored using a transponder on the ocean floor.

(As an aside to the above description it can be noted that the anchor line for the vessel was a composite moor consisting of 10,000 ft. of 1/8" wire rope and about 1000 ft of 3/8 nylon rope. The anchor was a 90 lb Danforth with a chain pennant and a 200 lb line sinker. This anchor held the 85' vessel for some 24 hours until a storm developed and the anchor dragged. While anchored the occasion developed to evacuate, via Coast Guard helicopter, a crew member who had collapsed from diabetic attack. There was some difficulty in convincing the helicopter crew that the vessel was indeed anchored.)

6.0 RESULTS

6.1 Laboratory Tests

For the fishbite moorings it was necessary to monitor strumming information and fishbite events. Since the mooring line was expected to be damaged by fishbite the usefulness of installing strumming sensors such as accelerometers was not deemed viable and it was necessary to limit the strumming measurement to a single measuring location at the upper end of the cable. As described earlier strain gages were used as primary strumming sensors.

An experiment was performed in the laboratory to determine the feasibility of using strain gages to detect strumming. The apparatus is shown in Figure 20. A 3/4" diameter dacron line was used to span 25 ft. from the fixed end shackle with the strain gage mounting to a pulley on the other end. Tension was supplied by hanging a 500 lb. weight on the end of the line. A variable speed exciting motor was used to vibrate the rope at its natural frequency of 7 Hz.

The data from this experiment consists of oscilloscope traces from the strain gage and from an accelerometer mounted on the rope. A visual observation of maximum lateral displacement was also recorded. The output and the strumming displacement were correlated, see Figure 21.

To get additional data on the effectiveness of our anti-strumming fairing, a water channel was used to observe the flows.

A 3/8" d. by 19" long piece of surgical tubing under a tension of 105 gms was used as the test cable. At 0.2 Kts. the cable strummed appreciably with an amplitude of $\pm$ 1 d. and a frequency of 1.7 Hz. The mode excited was the transverse fundamental. When the tension was increased, the vortices would be shed at the same time and the tubing would oscillate in the same plane as the flow vector at roughly twice the frequency.

Flow visualization in the form of injecting dye into the water was used to evaluate the effect of the fairings on von Karman vortex street formation. Figure 22a shows a typical von Karman vortex street being generated behind a bare cable. Four 3" wide fairings were put on the tubing with about 1" spacing between them. Figure 22b shows that there is no organized shedding between fairings with this spacing. There was also no noticeable strumming. As the spacing was increased between fairings, organized shedding took place at about 1" away from the edge of the fairing. The number of fairings was reduced from 4 to 3 to 2 to 1. Even through there was correlated shedding between fairings, the strumming was not noticeable until only one fairing was used, and even then it was very small compared with the no fairing strumming. The reason for this, of course, is that the fairing was enough to destroy the correlation between the strumming on either side.

6.2 Chesapeake Bay Tests

The strumming information from the two 100' samples was recorded on magnetic tape along with current information. Strumming for this short length was resonant with excitation, for the unfaired cable, from the third to the eight harmonic. In many instances two frequencies were co-existant. Figure 23 shows a spectra for one of the recorded samples. Strumming at both 3.8 Hz ($n = 4$) and 4.9 Hz ($n = 5$) was present at large amplitude. Peak accelerations for this situation were about 1.5 g. By comparison the faired cable strumming spectrum is shown with the same amplification factor and for an approximately equal current. The peak frequency was 2.5 Hz and the amplitude reduced significantly. Peak accelerations for the faired cable were about 0.05 g. In general this type of fairing reduced amplitudes by about a factor of 8 and accelerations by a factor of about 32.

The significant frequency shift is demonstrated in Figure 24. A consistent correlation of strumming frequency with excitation current is seen. Note that the unfaired cable appears to correlate with:

$$f = .12\, u \cong \frac{0.2\, u}{1.6\, D}$$

and this can be interpreted as a cable with effective diameter of 1.6 times the actual diameter.

Although the faired cable data is more limited it can be said that in general the frequencies are reduced by a factor of two. As noted earlier amplitudes were almost an order of magnitude lower.

The sharply reduced amplitudes meant that extreme care was needed to prevent data contaminations. The vessel was carefully examined for any oscillating cables or lines and each source systematically eliminated. To the eye and touch, the faired cable oscillations were indecernable. The strumming detected was still more than an order of magnitude above the noise floor of the electronics.

It was concluded from these experiments that the fairing and the sensors were satisfactory designs for the planned buoy experiment.

6.3 Moored Buoy Data

Strumming data for these buoys was recorded on board together with a record of time. This data was re-recorded on a Sangamo tape recorded and, with a DEC PDP 8 computer which was used as a variable speed sampler the amplitude and spectra of the strumming data examined. A Nicolet 411 Dual Channel FFT was used. It should be noted that data was recorded for a 4 second period and at 2 hour intervals. Figure 25 shows a sequence of such recordings during part of a relatively quiet tidal period. The development of the strumming during the tidal cycle is clearly seen. By comparison the faired cable shows very small strumming amplitudes.

A point in time corresponding to the maximum strumming response is demonstrated in Figure 26. The strumming buoy exhibits a wide band of strumming oscillations with peaks at 7.2 and 8.3 Hz. Referring to the Chesapeake Bay data (Figure 24) it would appear that excitation flows of over 1 knot were present. Peak accelerations were about 4 g.

By comparison the faired cable again showed reductions in both amplitude and peak frequencies. Peak amplitudes were reduced by a factor of 10 and peak frequencies by more than a factor of 2. (In figure 26 the faired cable amplitudes are increased to show the frequency content). Peak accelerations were about 0.1 g or reduced by about a factor of 40. These reductions were quite similar to those observed earlier.

It should be noted that the natural frequency for the unfaired moored cable is 0.04 Hz and therefore one question is whether the spectra of Figure 26 consists of a large number of high order modes of the natural frequency. The short period of the recording precludes any detailed examination of this. Therefore an additional experiment, using a wire suspended from the vessel was performed.

6.4 Long Wire Tests

The wire was suspended from the vessel and, for an 18 hour period, the strumming was recorded on magnetic tape. The location was identical to that of the southern "fishbite" mooring. The currents observed followed a generally tidal pattern as expected. Maximum currents were about 0.7 knots. The vessel remained remarkably still during the recording and motion over the bottom never exceeded 0.05 knots. Figure 27 shows part of a LOFAR grain where the spectral history of the strumming is shown for a 20 minute period. The strumming recorded is rarely steady and a 5 minute period of reasonally steady strumming is rare. One period of approximately 25 minutes where the strumming was sufficiently steady was located and the strumming signature is shown in Figure 28. A typical wide band signature centered around 10 Hz is seen. This was expanded as shown in Figure 29. No fine line structure, corresponding to multimodes of the natural frequency (.025 Hz) were seen. This really should be expected since the attenuation length is estimated to be about 25 meters (at 10 Hz) for the wire.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Although the experiment did not proceed completely as planned certain conclusions can be shown. These are:

Long ocean moorings, long compared with the attenuation length, strum with both standing and travelling waves and their strumming amplitudes are similar to short resonance cables.

The variability of the strumming signature is high and presumably reflects the variability of the environment. Hence the acoustic signature is a broadband, low frequency noise which fluctuates considerably with time.

It should be noted that the strumming sensor that identified the broadband signatures on long cables also recorded the expected resonant strumming on short cables. Hence the length of the cable is, presumably, the difference between the two types of signature.

The anti-strumming fairing shown is reasonable in cost, reasonably easy to handle and quite effective in reducing strumming. Acceleration were reduced by about 2 orders of magnitude and in addition frequencies were reduced.

The faired cable buoy had dipped significantly less than the unfaired cable as observed during the recovery operation. While only a qualitative measure the conclusion that the antistrumming fairing reduced the drag coefficient was inescapable and this drag reduction could be as much as 50%.

The lack of fishbite events did not reflect a lack of fish. A number of sharks were seen during deployment and recovery including a small lemon shark. A large fish population was seen on bathymetry during recovery of the buoys.

Two possible explanations for the lack of fishbite attack seem possible. First that the food supply in the Tongue of the Ocean is high enough that none of the biters were motivated. A second possibility is that the nature of the acoustic signature is important and that the wide band non-resonant strumming signatures do not induce attack.

It is important to note that operators of acoustic arrays, supported by long cables similar to those used here, would see a strumming signature which is not as readily recognized as single or dual line signatures and may think such signals are flow noise or ocean background noise.

It is recommended that this experiment be repeated, in the Bermuda area, with three moorings. The third additional mooring could be constructed with strong nodal points in the mooring to produce resonant strumming. This mooring would be similar to the Woods Hole Oceanographic Institute current meter moorings used for MODE and similar programs.

8.0 REFERENCES

1. Engel, M. J. and Starkey, R. J., "A Literature Survey of Fishbite of Oceanographic cables, "General Electric Co., December 1974.

2. "Environmental-Acoustics Atlas of the Caribbean Sea and Gulf of Mexico," Volume II, Marine Environment, U. S. Naval Oceanographic Office, Report No. SP-189II, Washington, D. C., August 1972.

3. Ramberg, S. E. and Griffin, O. M., "Some Transverse Resonant Vibration Characteristics of Wire Rope with Application to Flow - Induced Cable Vibrations", NRL Report 7821, December 1974.

4. Dale, J., Menzel, H. and McCandless, J. "Dynamic Characteristics of Underwater Cables Flow Induced Transverse Vibrations", U. S. Naval Air Dev. Center, Report No. NADC-AE-6620, September 1966.

TABLE 1

SUMMARY OF FISHBITE FACTORS

	Ranking*
vs. Attacking Species	1. Sharks 2. Sea Turtles 3. Paralepididae 4. Lancet Fishes 5. Other bony mandibular types 6. Cephlapods 7. Marine Mammals 8. Mollusks/Crustaceans
vs. Cable Type	1. Natural Fiber Rope, Unarmored 2. Synthetic Fiber Rope, Unarmored 3. Flexible Plastic Jacketed Fiber Rope 4. Semi-Rigid Plastic Sleeved Fiber Rope 5. Plastic Jacketed Steel Wire Rope (or Armored Cable) 6. Semi-Rigid Plastic Sleeved, Coated Steel Wire Rope 7. Corrosion Resistant Hi-Strength Alloy Wire Rope w/smooth cut-resistant plastic jacket
vs. Cable Armor - Materials:	1. Polyethylene, Polypropylene, Polyurethane, Nylon 12 2. Polycarbonate, Polyvinyl Chloride, Nylon 6/6 3. ABS, Acetal, Polyphenylene Oxide Resins, Polysulfone (Modified) 4. Galvanized Steels 5. Corrosion Resistant Hi-Strength Alloys
- Method:	1. Coating 2. Integral Jacket 3. Sleeve a. Braided b. Spiral c. Smooth

*Lower number indicates greater potential damage.

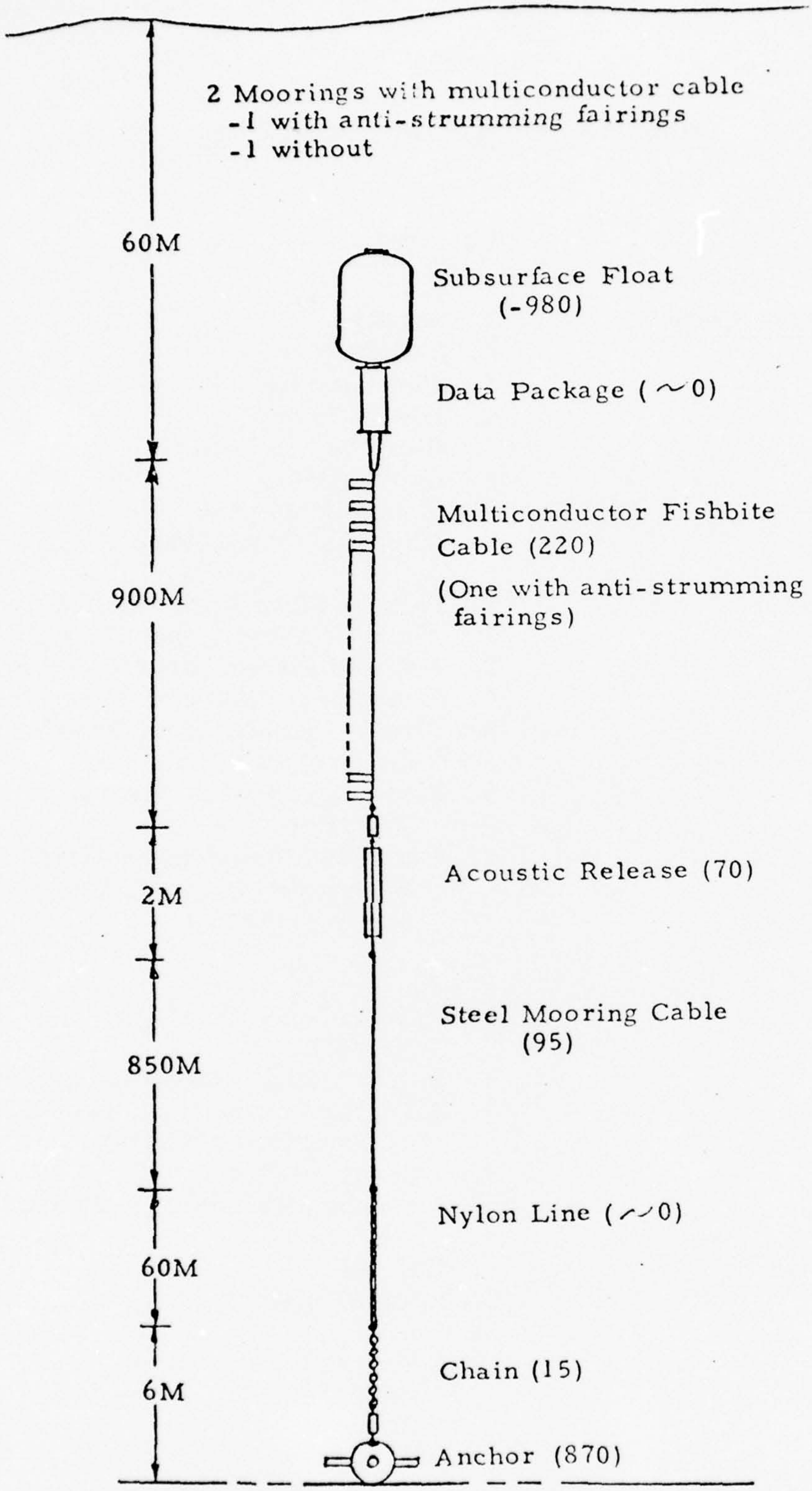


Figure 1. Fishbite Experiment Mooring Layout

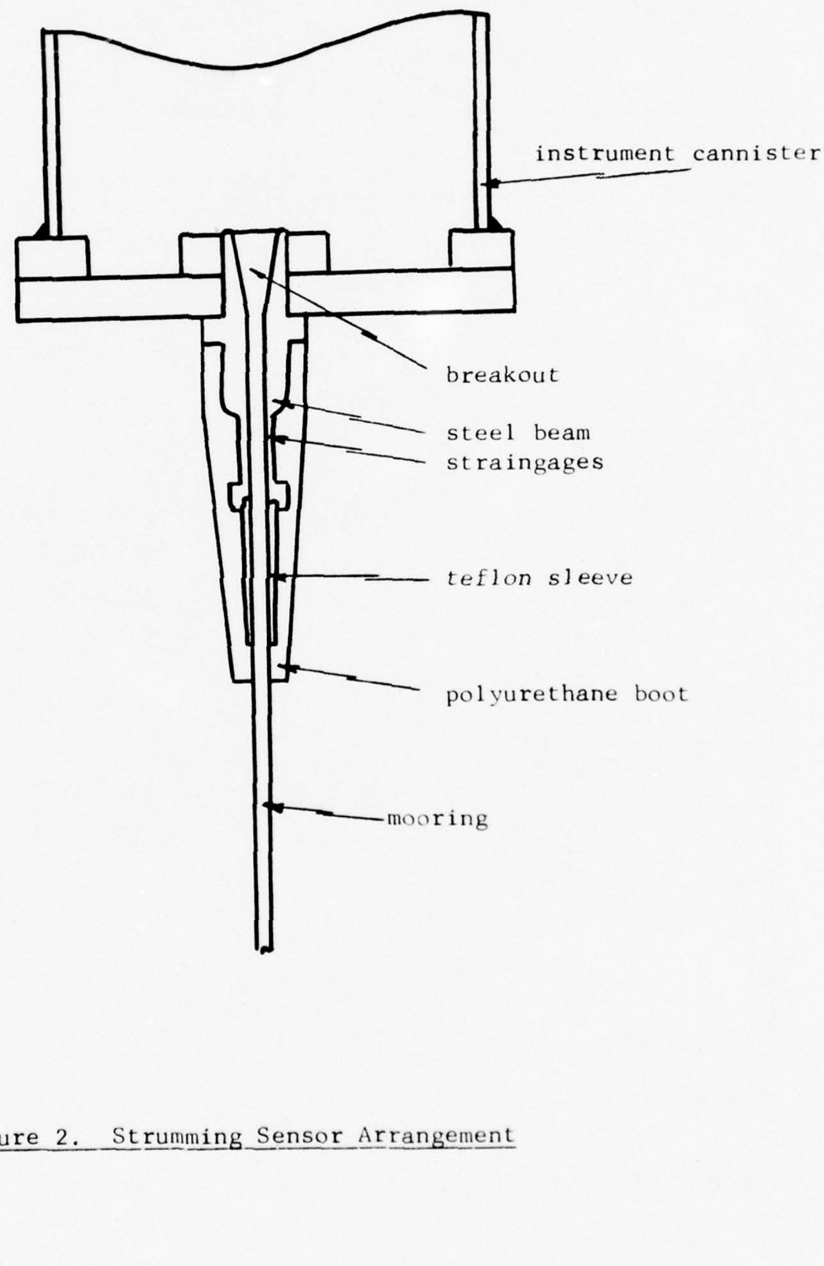
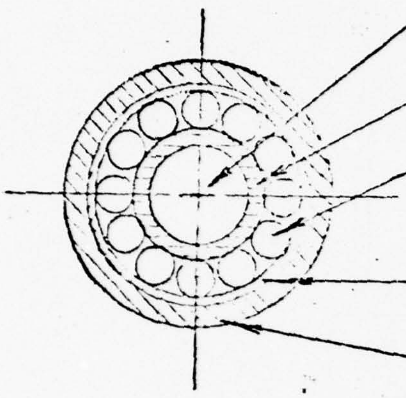
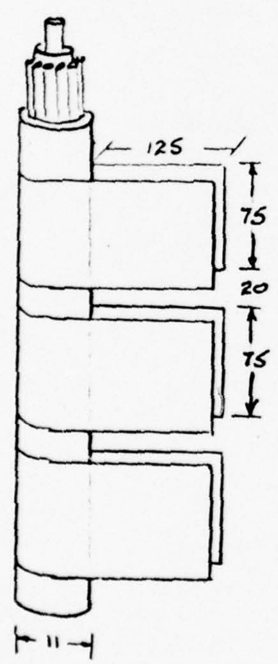


Figure 2. Strumming Sensor Arrangement

CROSS SECTION SKETCH	DESCRIPTION	O.D.
	STRENGTH MEMBER 5/32" (1x19) Galvinized Aircraft Wire Rope; Minimum Breaking Strength, 3200 lbs.	.156"
	JACKET Polyvinylchloride.	.216"
	CONDUCTORS 12 units AWG #20 (7x.013") Bare Annealed Copper Wire with .012"-.014" wall of low density polyethylene Insulation; in polarized pattern.	(.060" .336"
	BINDER TAPE .008"-.012" mylar. Tape, double layer (½ lap)	.372"
	OUTER JACKET .045"-.050" wall, low density polyethylene, black	.470"
		±.030"



CABLE: 1 x 19 WIRE ROPE
12 CONDUCTORS
BLACK LDPE JACKET
11 mm DIAMETER

FAIRING: FLAT LDPE SHEET
1.5 mm THICKNESS

DIMENSIONS - MM.

Figure 3. Details Of The Multiconductor Cable With Anti-Strumming Fairing Attached

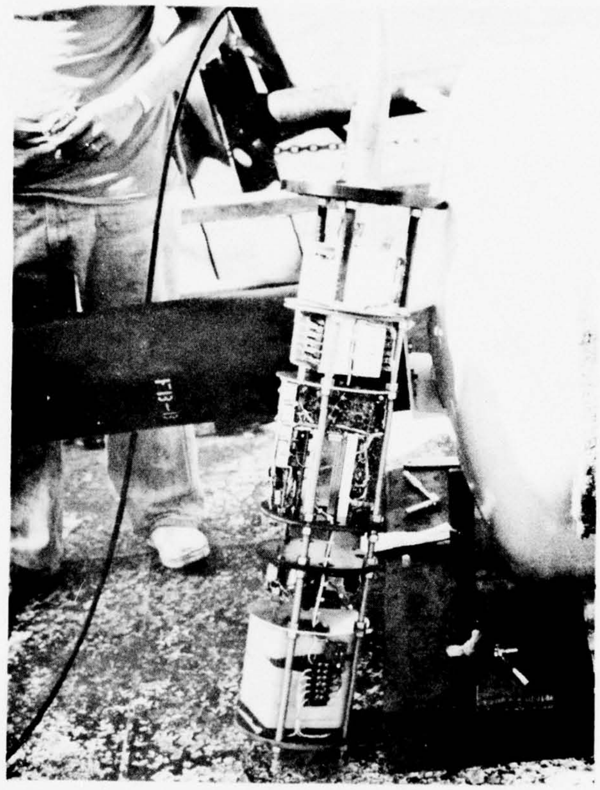


Figure 4. Electronic Package Prior To Deployment

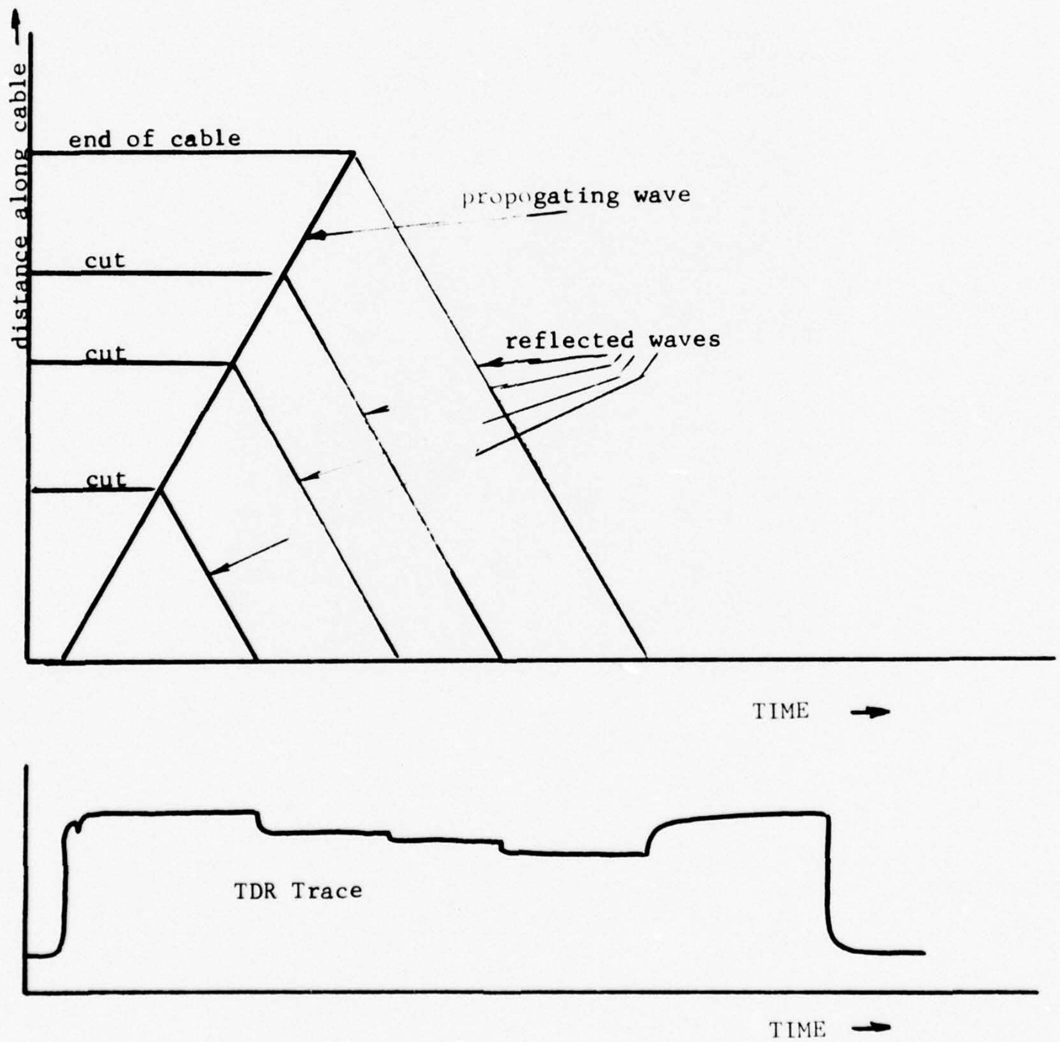


Figure 5. Example Of The Use Of Time Domain Reflectometry

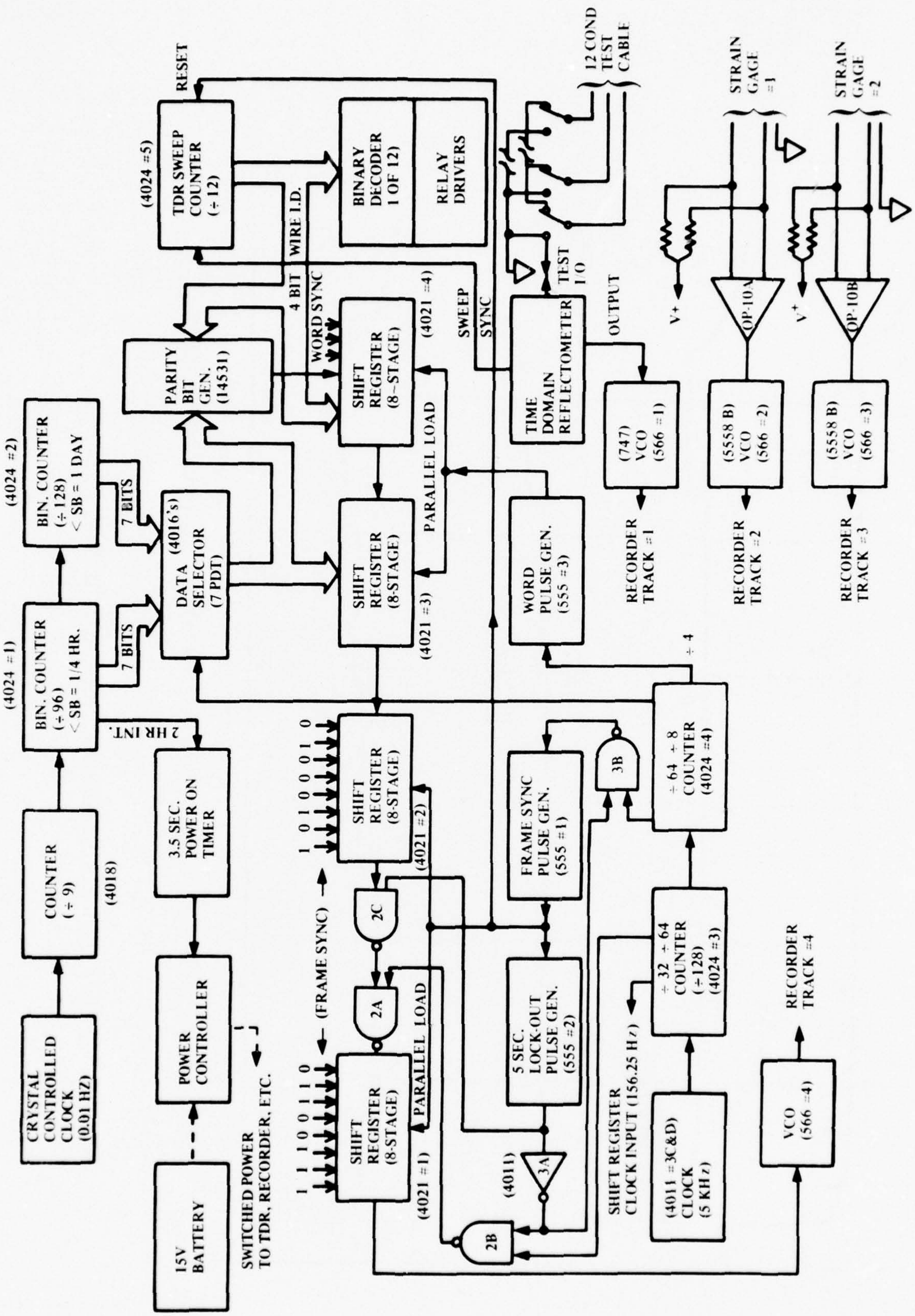


Figure 6. Block Diagram Of The Fishbite Electronics

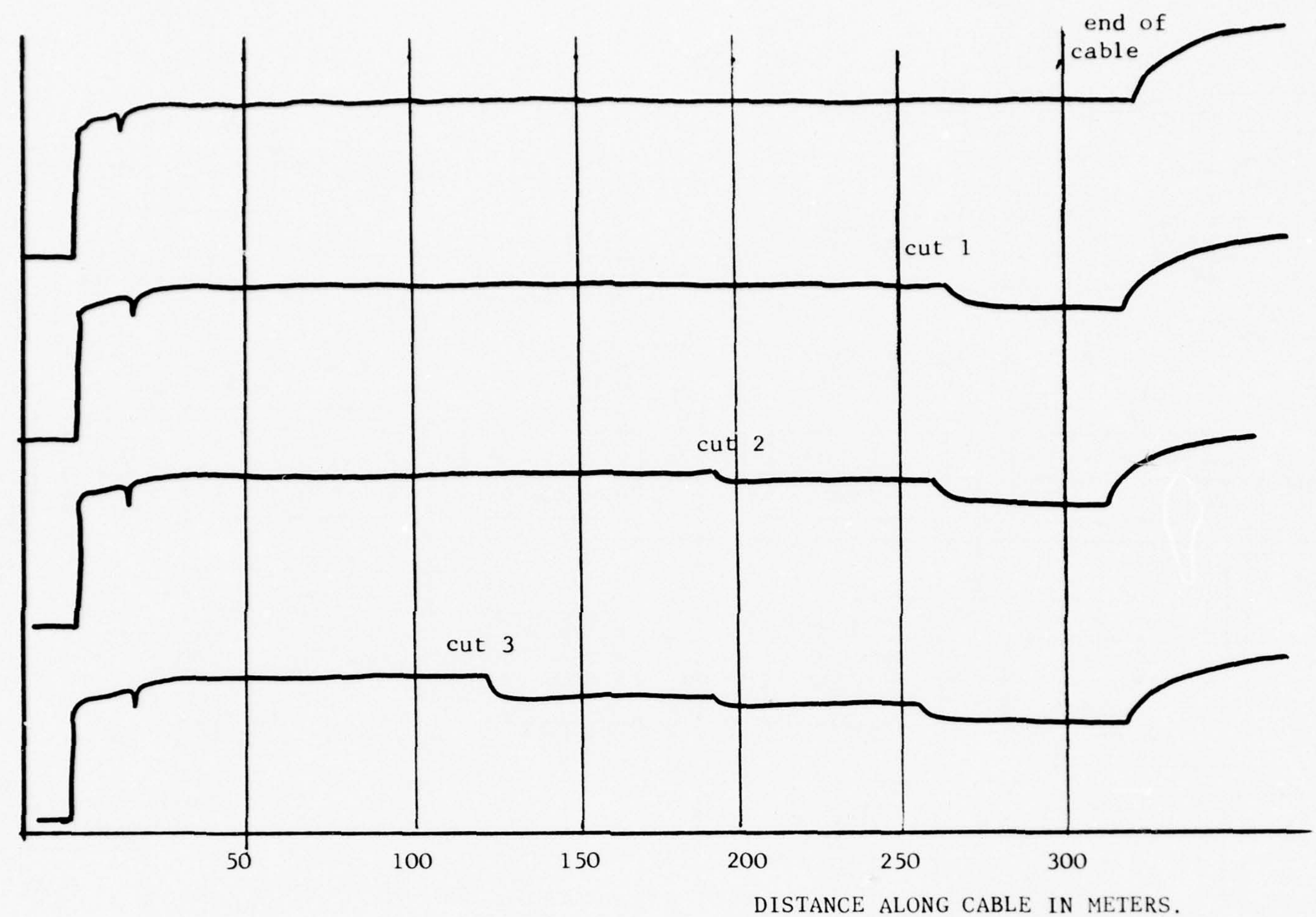


Figure 7. TDR Traces Showing Example Of Multiple Cuts

Figure 8. "VAYU" With Strumming Sensor Attached At Bow

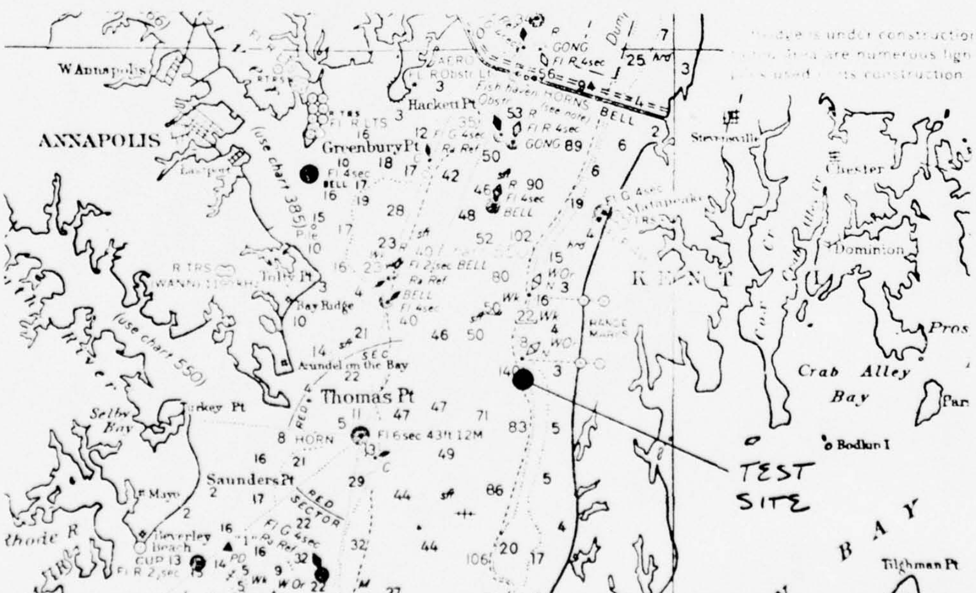


Figure 9. Chesapeake Bay Test Site (Near Annapolis)

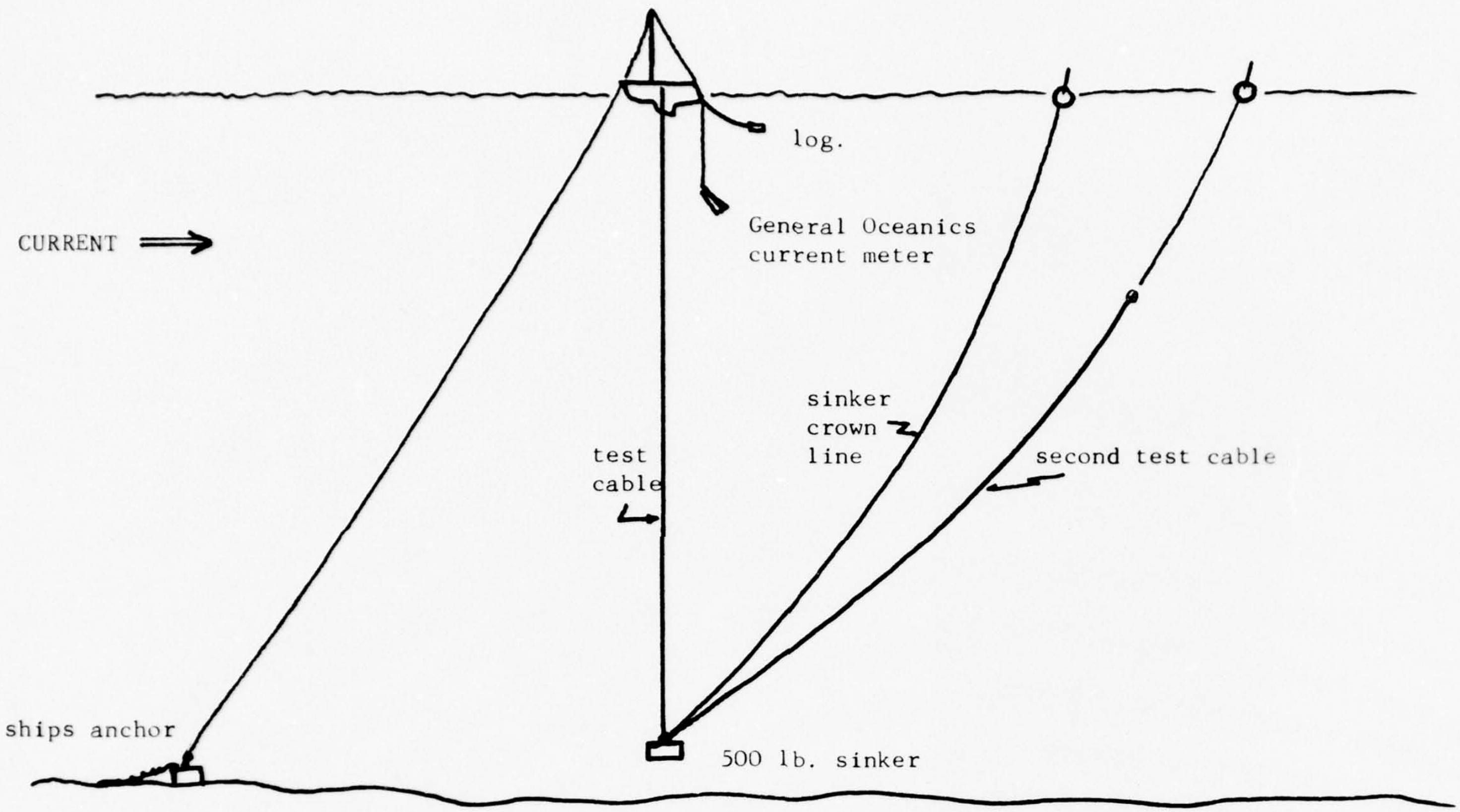


Figure 10. Chesapeake Bay Experiment Configuration

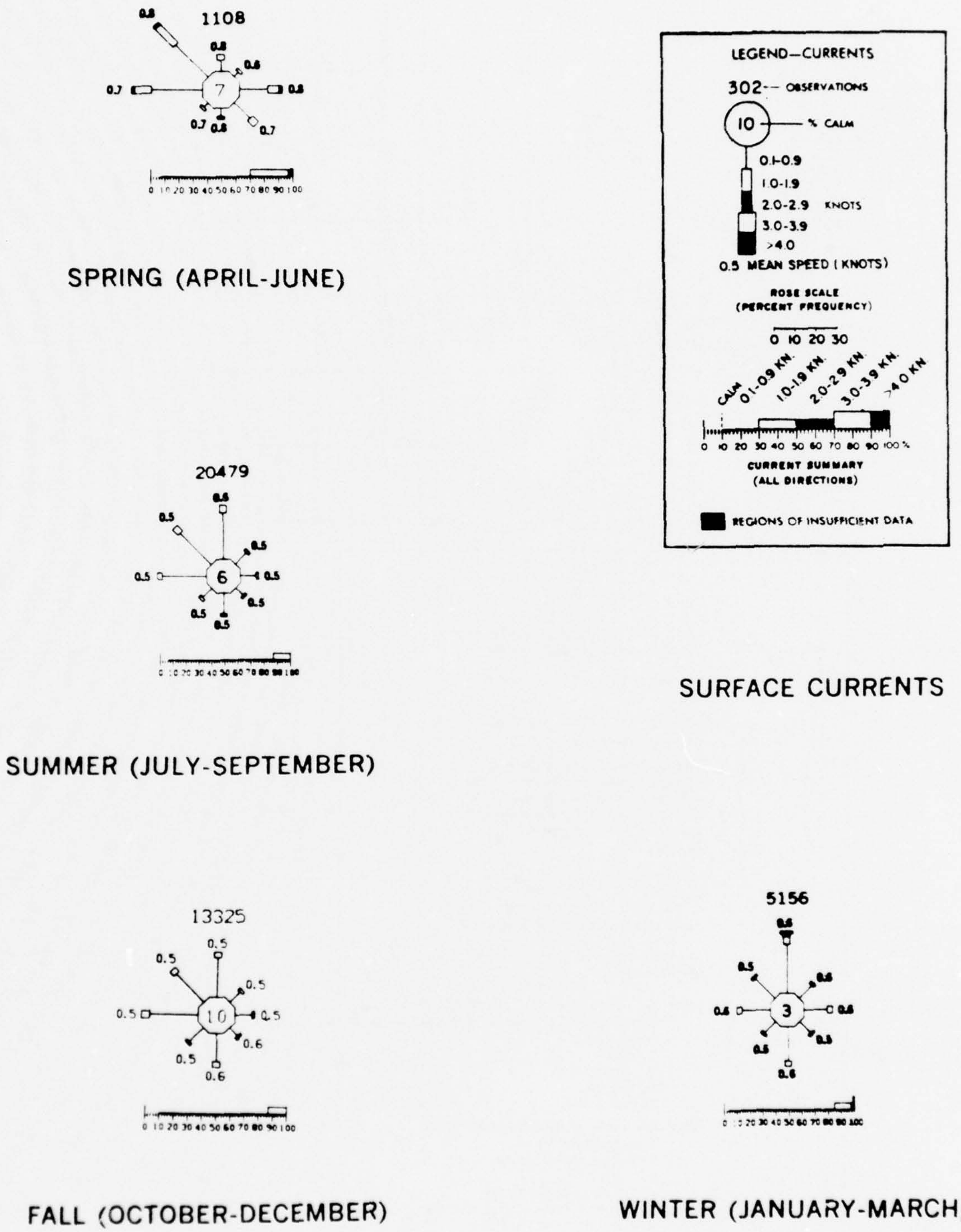


Figure 11. Surface Currents In The Tongue Of The Ocean

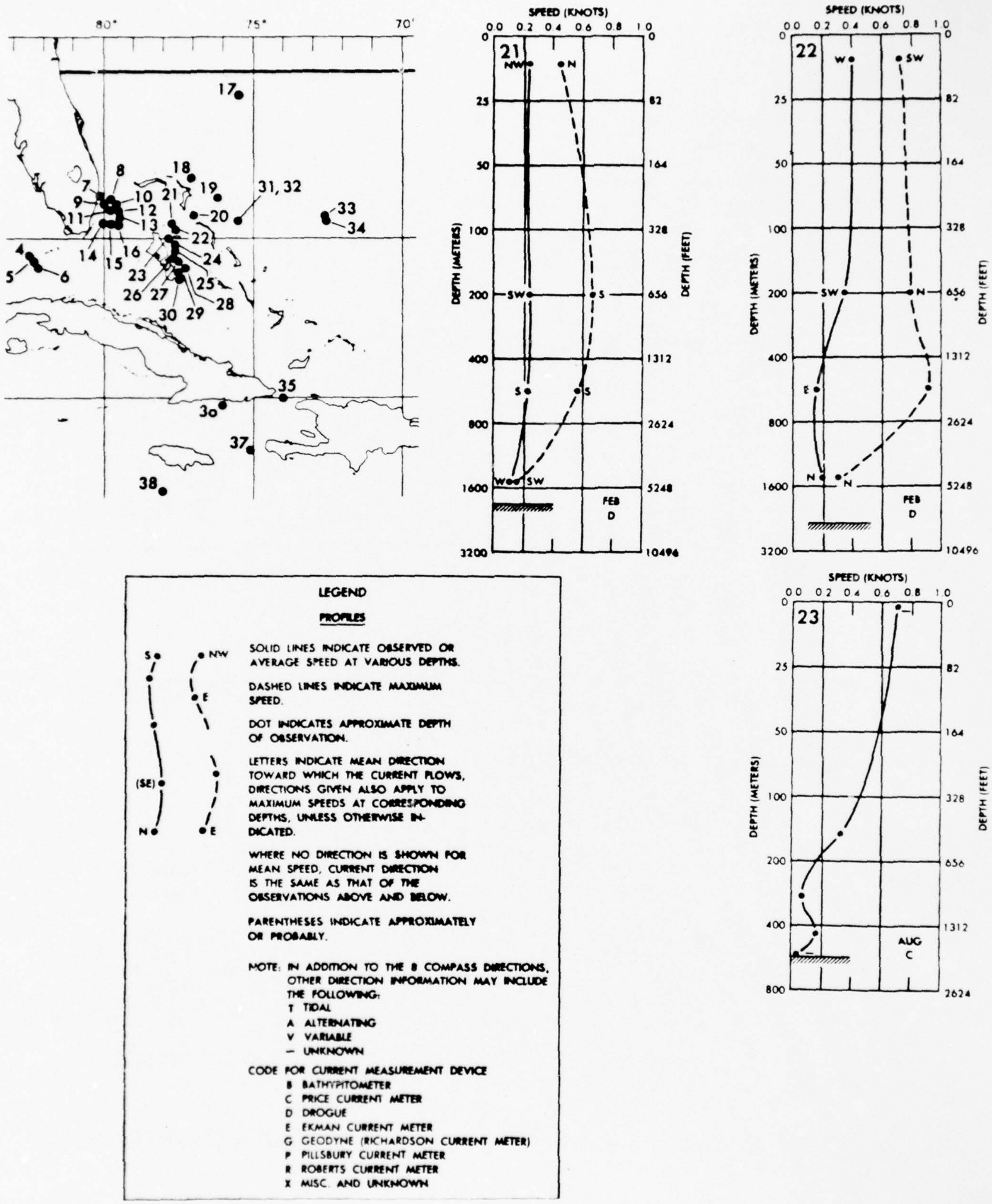


Figure 12. Subsurface Currents In The Tongue Of The Ocean (Northern Portion) ref.2

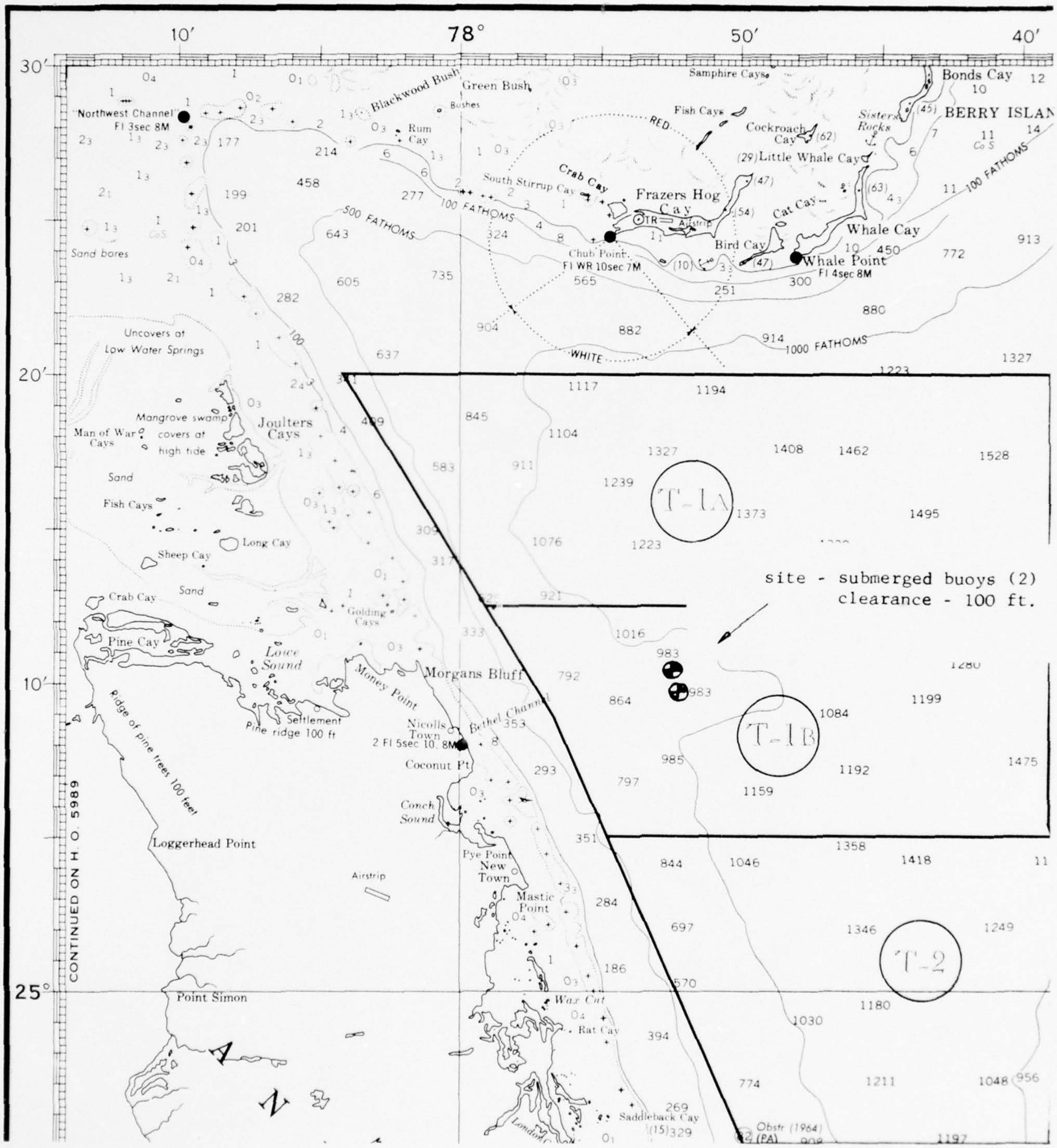


Figure 13. Site Of Fishbite Experiment
(Northern Portion TOTO)

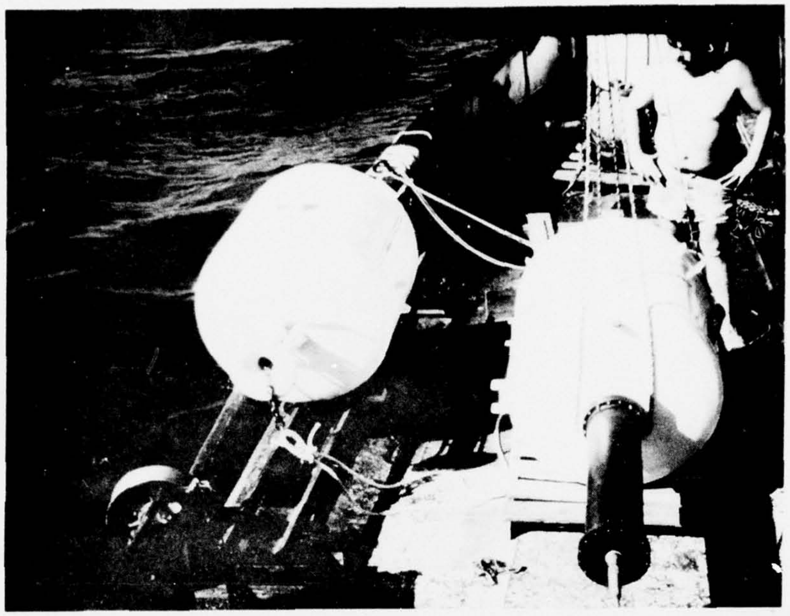


Figure 14. Fishbite Mooring And Float On Deck Prior To Deployment.

Figure 15. Float Launch (Anchor Seen In Right Hand Corner)

Figure 16. Skiff Towing Out Mooring And Float

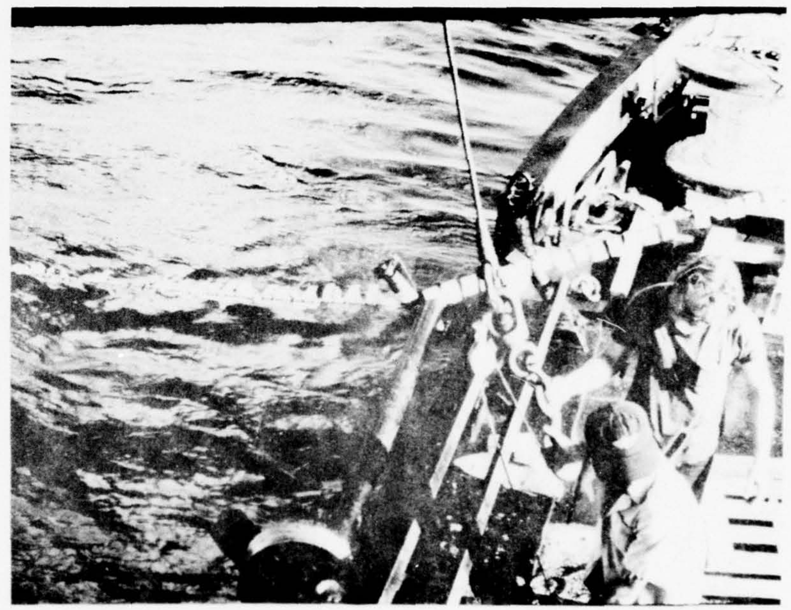


Figure 17. Deployment Of The Faired Cable

Figure 18a. Skiff tows float and buoy while ship deploys mooring assembly.

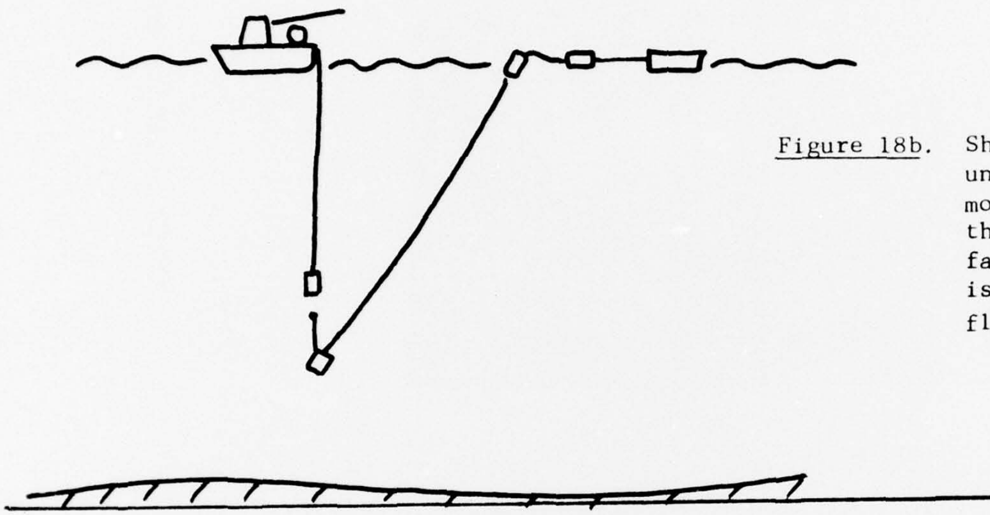


Figure 18b. Ship lowers anchor until in a near vertical mooring condition and then releases. The anchor falls until the system is supported by the float.

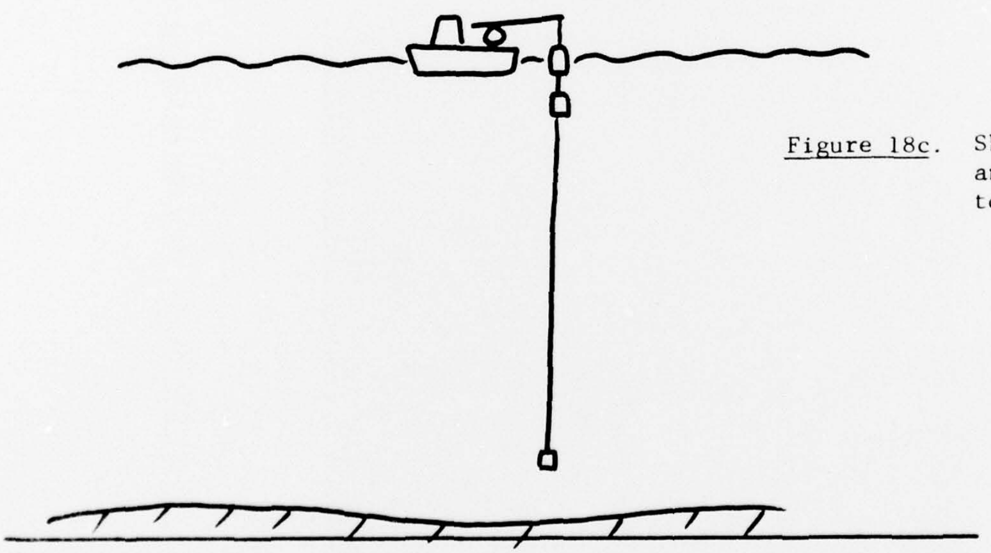


Figure 18c. Ship removes float and lowers mooring to depth.

Figure 18. Illustration Of The Deployment Sequence.

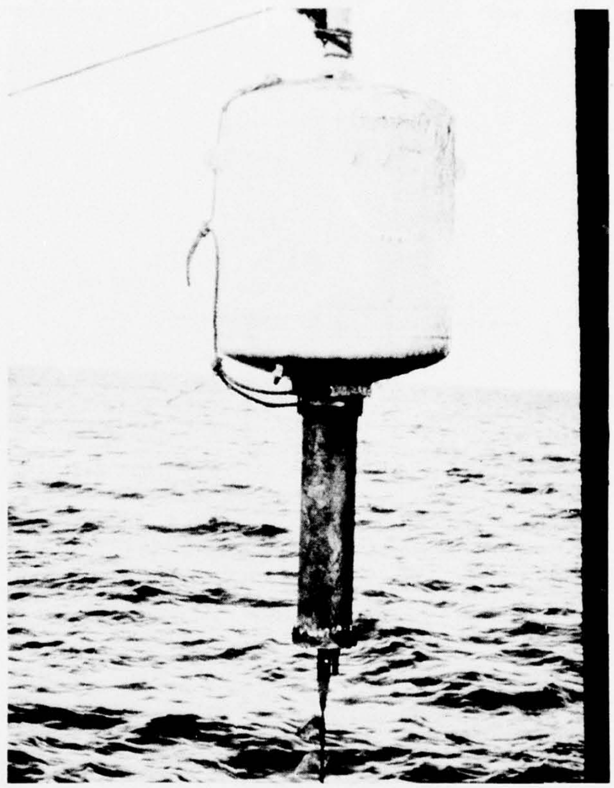


Figure 19. Retrieval Of Moorings

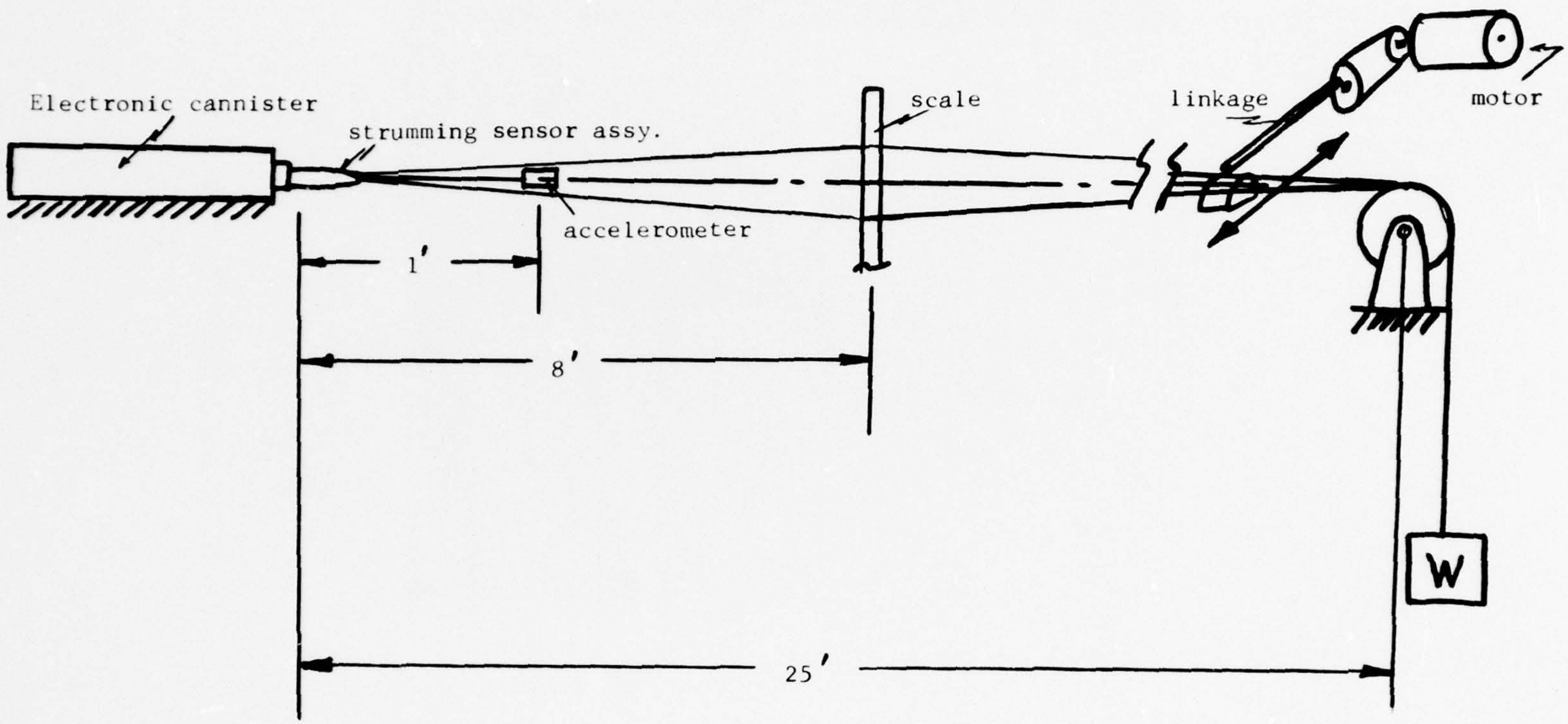


Figure 20. Laboratory Apparatus For The Calibration Of The Strumming Sensor

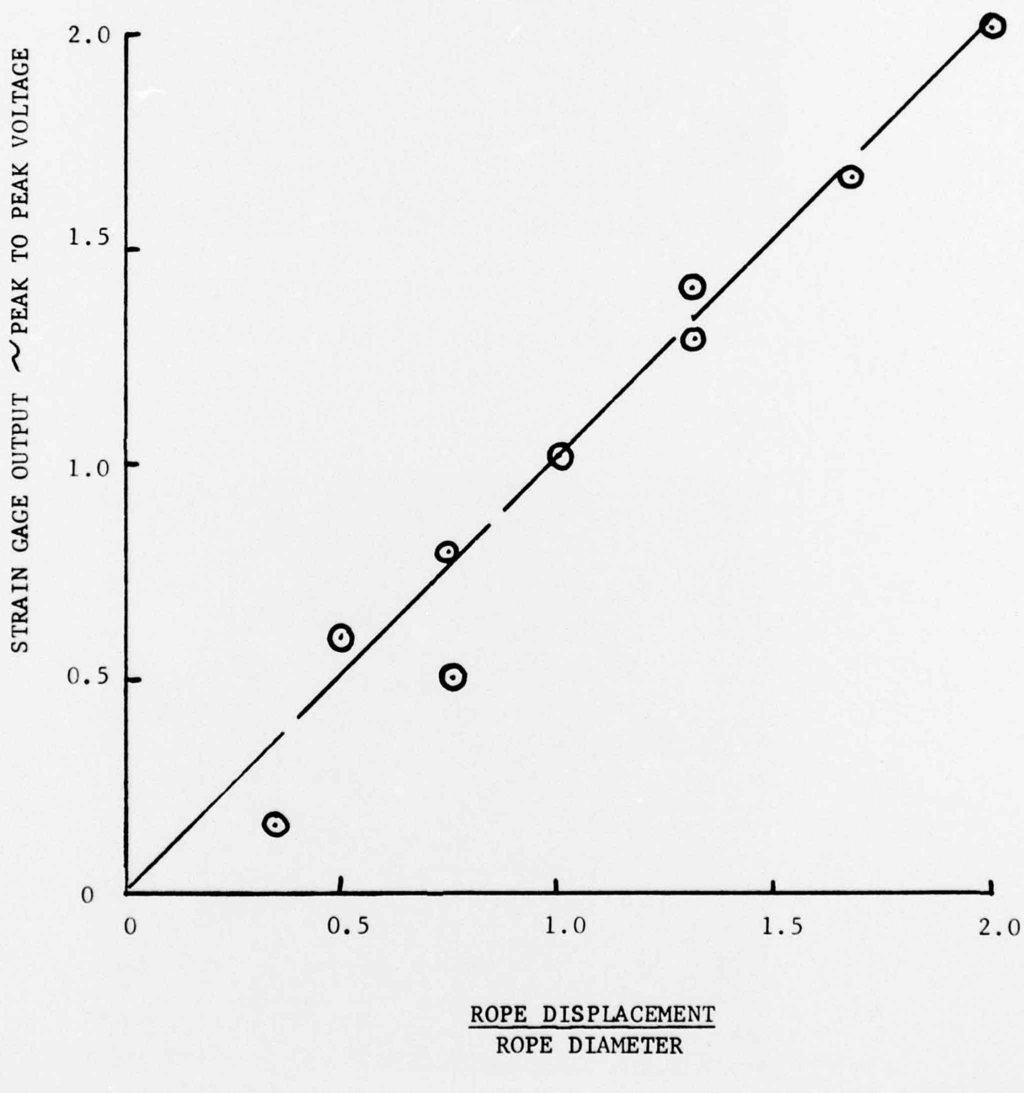
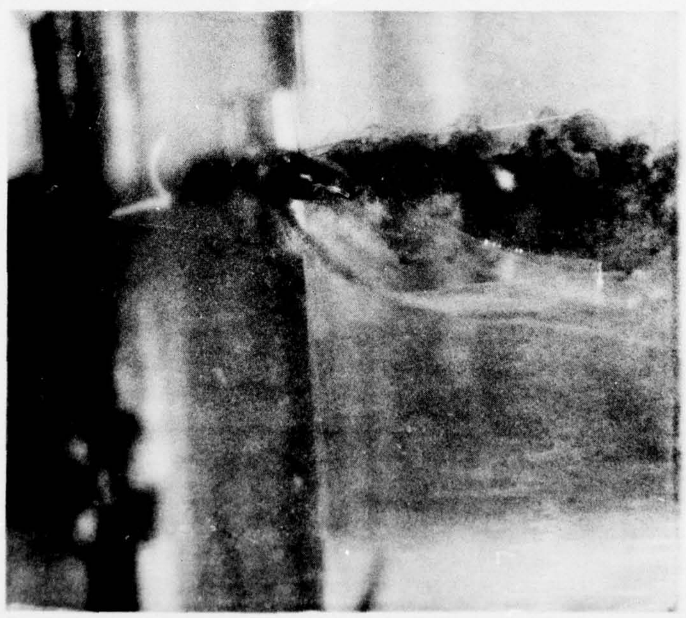


Figure 21. Results Of Strumming Sensor Calibration

a. Vortex Shedding from Bare Tubing



b. Turbulent Wake from Tubing with Anti-Strumming Fairings Attached

Figure 22. Water Tunnel Test Of Anti-Strumming Fairing

(velocity of 0.2 knots)

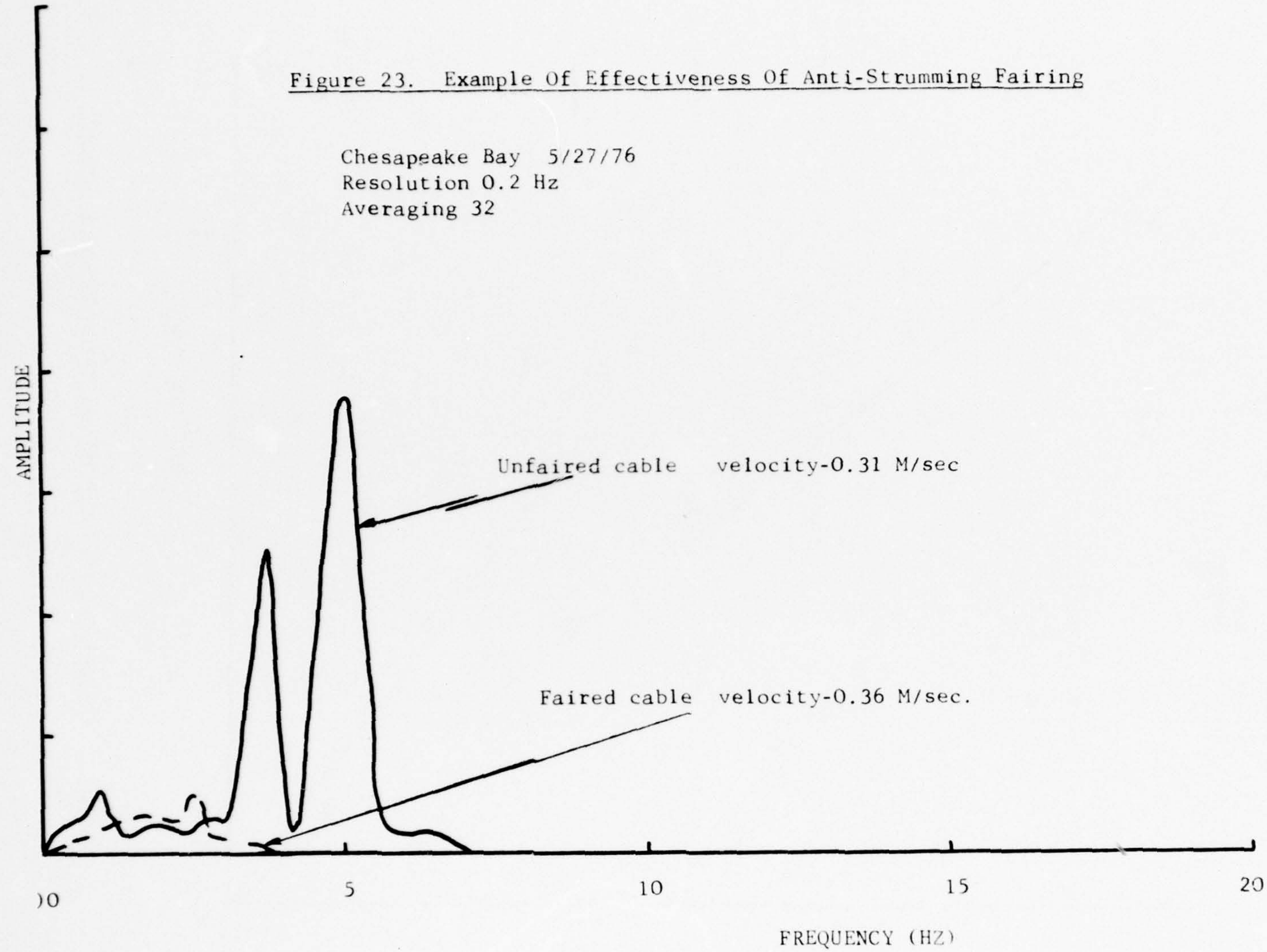


Figure 23. Example Of Effectiveness Of Anti-Strumming Fairing

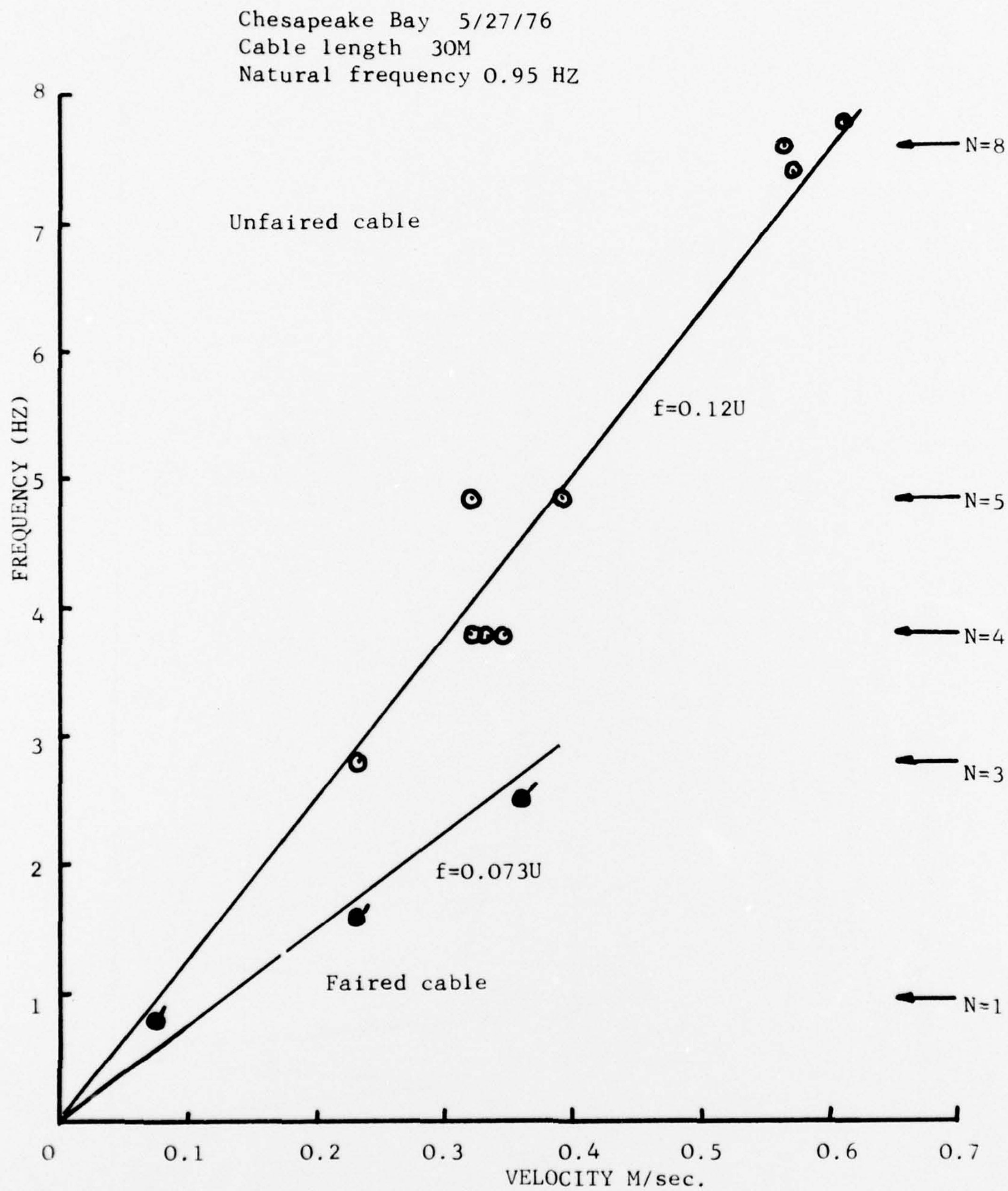
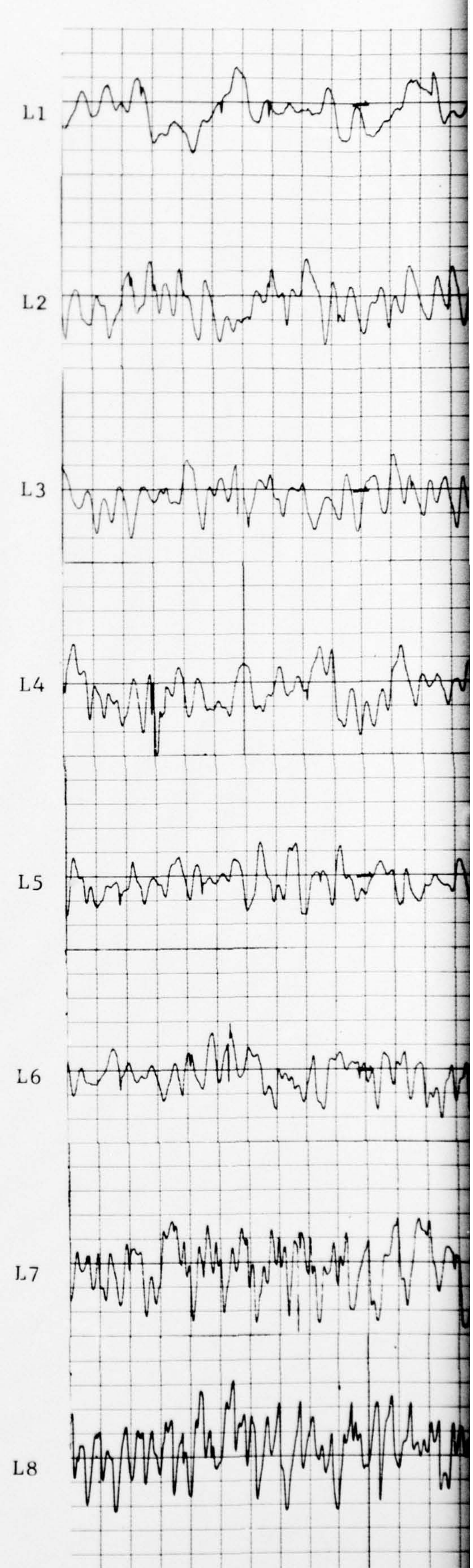
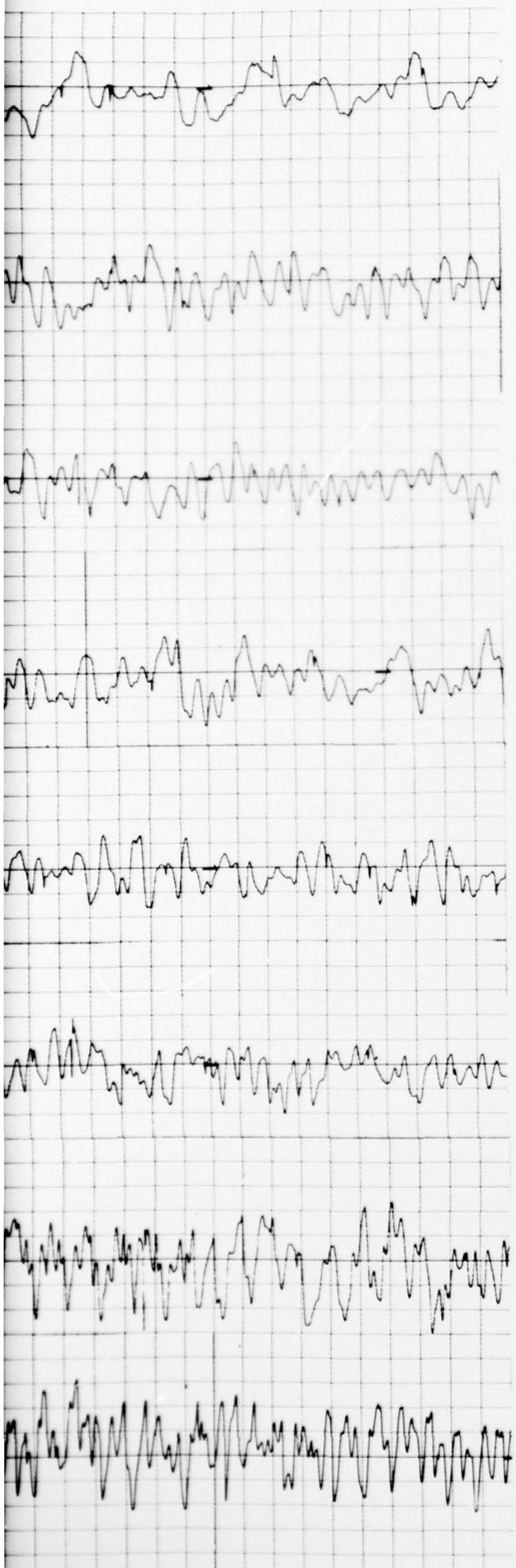


Figure 24. Effect Of Anti-Strumming Fairing On Frequency

TOTO 9/23/76
Data recordings are 4 seconds in duration and separated by about 2 hours. L1 marks the time when the current (as estimated) is at a low. The gradual increase in current can be seen qualitatively in the strumming signature development.





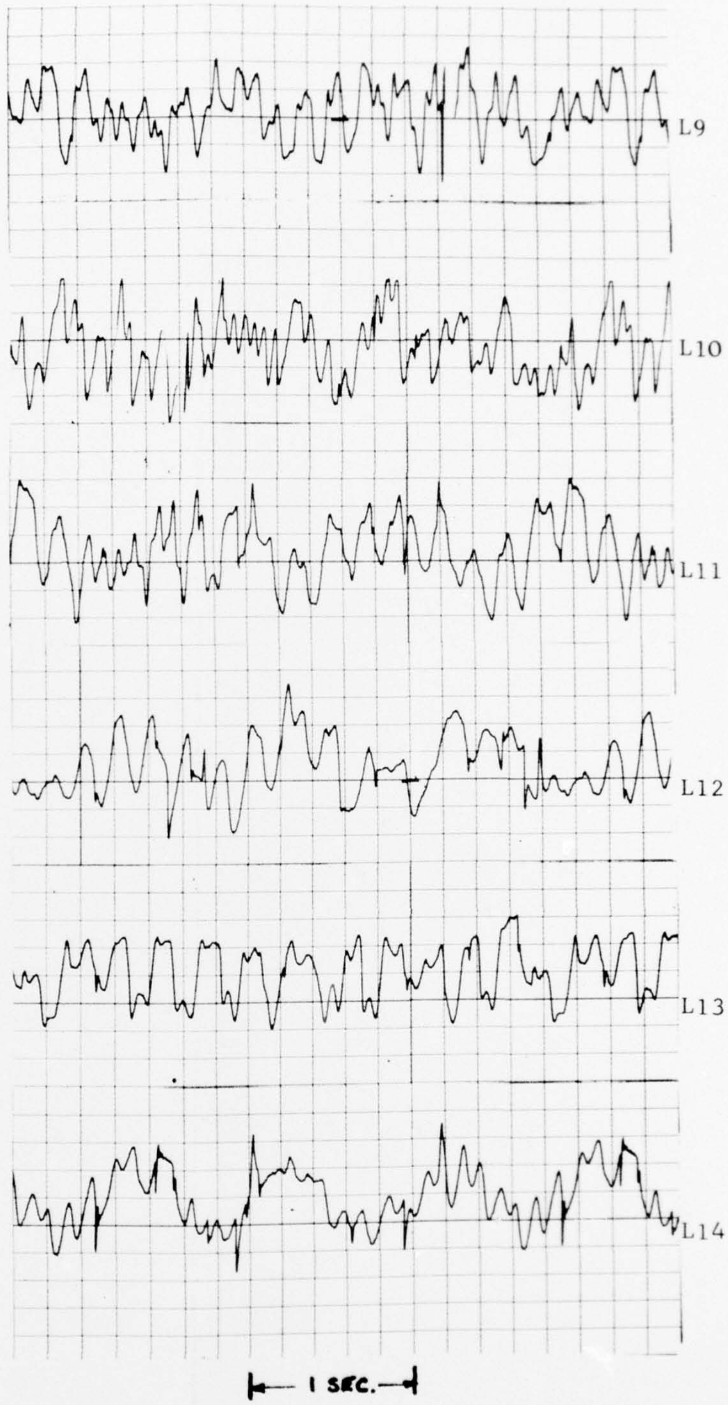
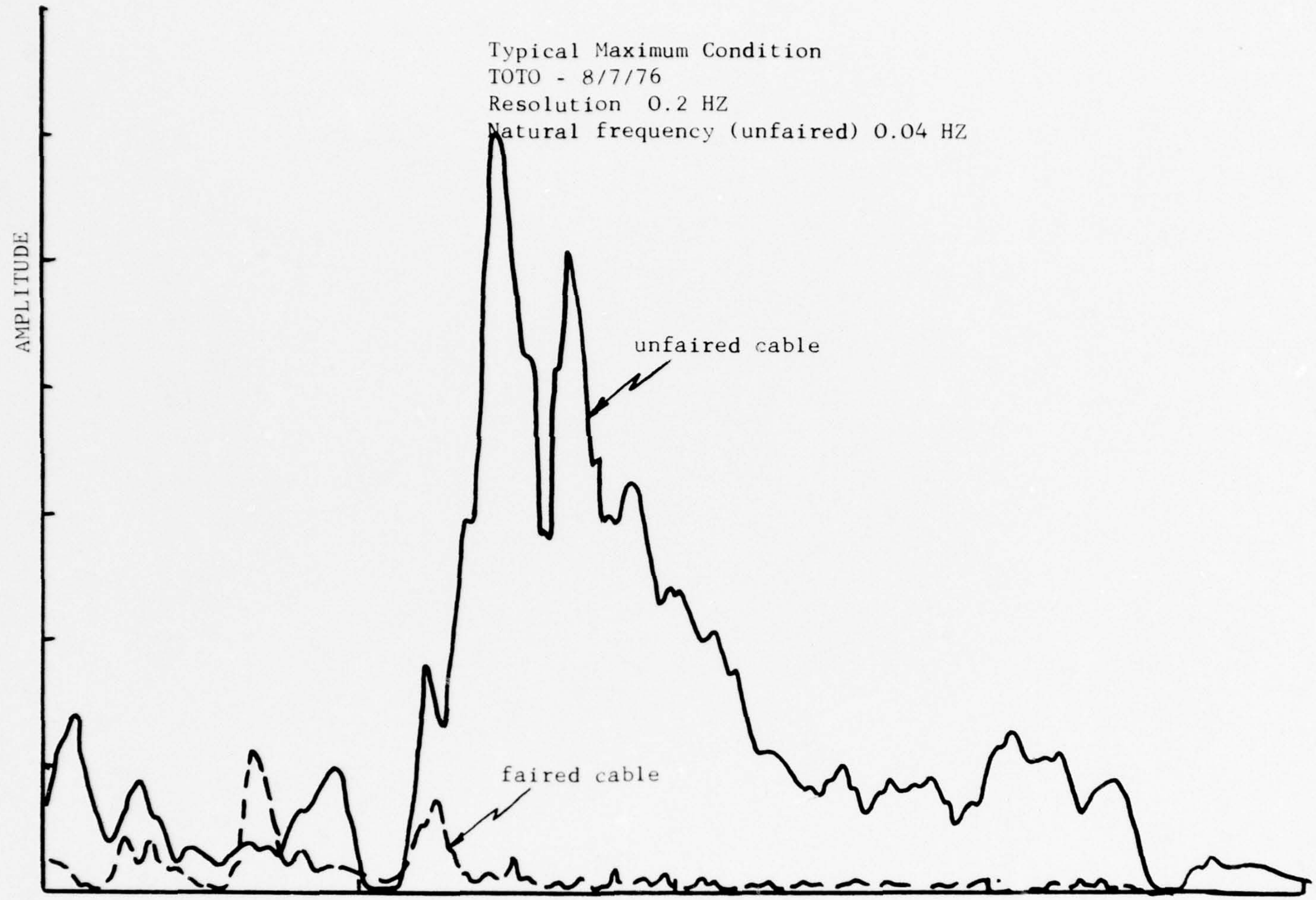


Figure.25. Strumming Signals From The Unfaired Mooring.

Figure 26. Comparison Of The Strumming Spectra For The Two Moored Buoys.



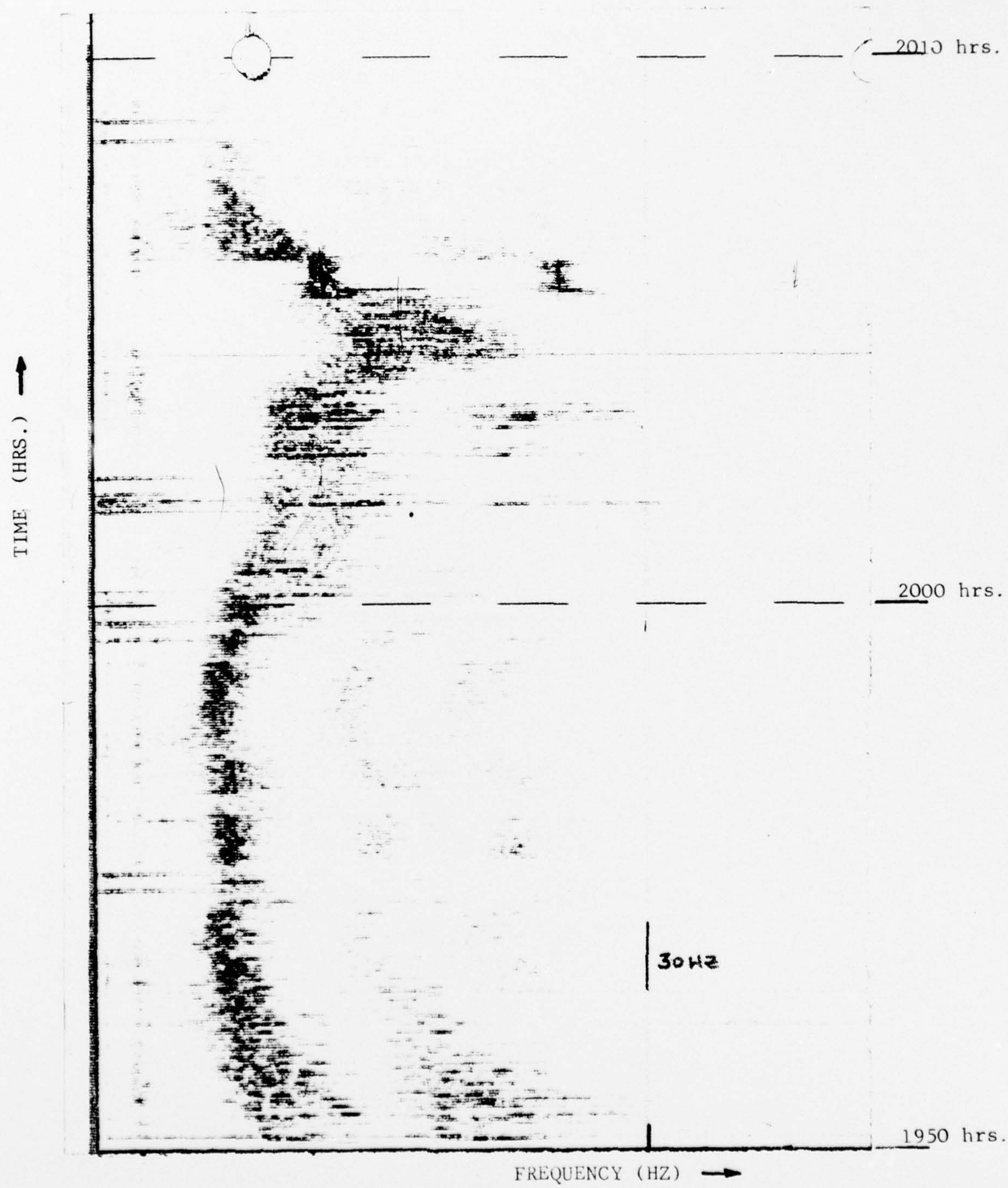


Figure 27. Lofargram Showing Typical Variability Of The Strumming. (Intensity Is Proportional To Amplitude)

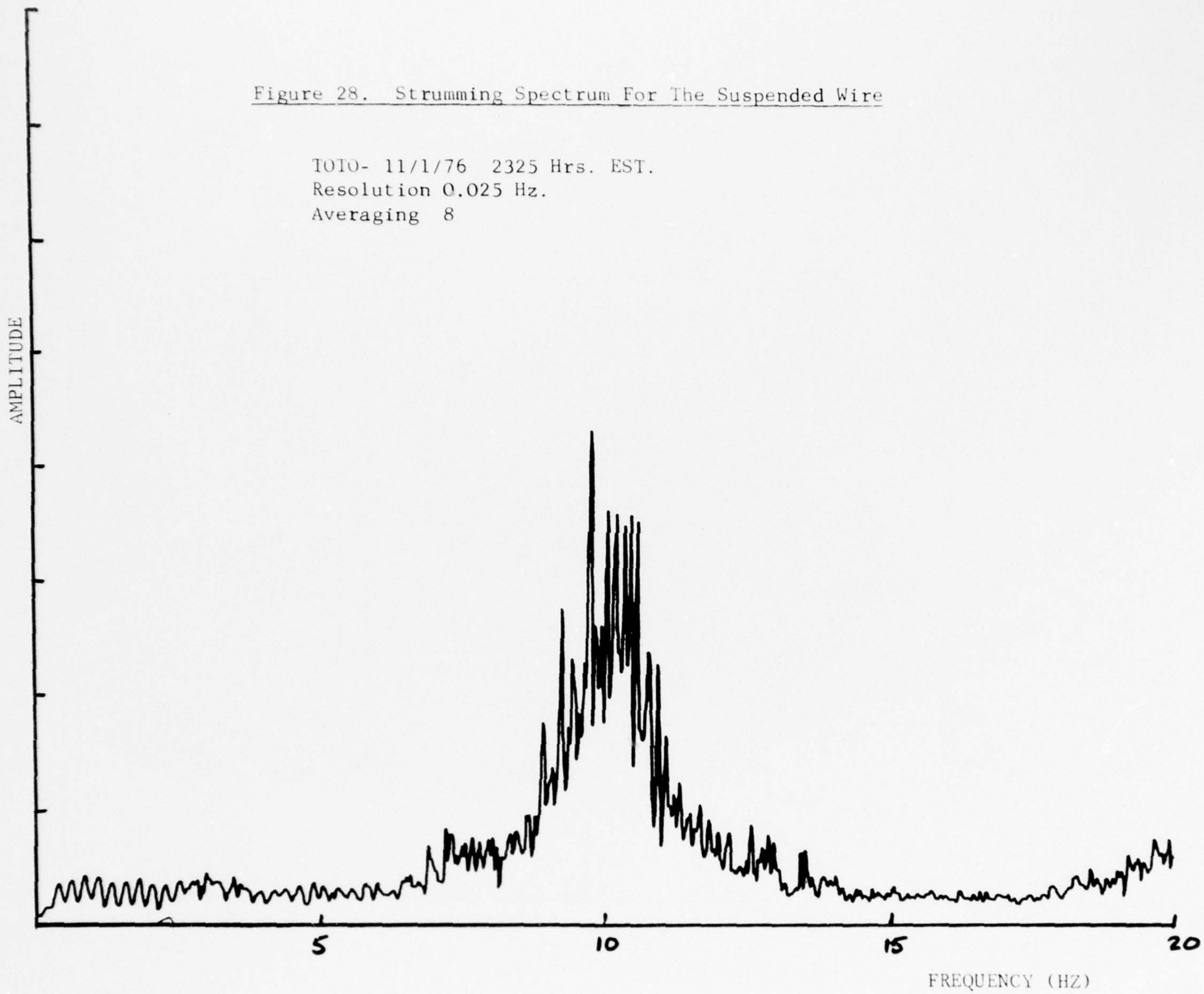


Figure 28. Strumming Spectrum For The Suspended Wire

Figure 29. Expanded Strumming Spectrum For The Suspended Wire